

EXPLORER OF
THE HUMAN BRAIN

The Life of
SANTIAGO RAMÓN Y CAJAL

BOOKS IN THE LIFE OF SCIENCE LIBRARY

THE LIFE OF SCIENCE

Essays in the History of Civilization

BY GEORGE SARTON

VICTORY OVER PAIN

A History of Anesthesia

BY VICTOR ROBINSON

BENJAMIN SILLIMAN

Pathfinder in American Science

BY JOHN F. FULTON AND ELIZABETH H. THOMSON

SUN, STAND THOU STILL

The Life and Work of Copernicus the Astronomer

BY ANGUS ARMITAGE

THE STORY OF THE SHIP

BY CHARLES E. GIBSON

SCIENTISTS AND AMATEURS

A History of the Royal Society

BY DOROTHY STIMSON

SONS OF SCIENCE

The Story of the Smithsonian Institution and Its Leaders

BY PAUL H. OEHSE

JAMES WATT AND THE HISTORY OF STEAM POWER

BY IVOR B. HART

THE ALCHEMISTS

Founders of Modern Chemistry

BY F. SHERWOOD TAYLOR

EXPLORER OF THE HUMAN BRAIN

The Life of Santiago Ramón y Cajal

BY DOROTHY F. CANNON



PORTRAIT OF CAJAL AT 40, JUST AFTER HIS TRANSFER TO MADRID

(Courtesy of Dr E Horne Craigie, Professor of Comparative Anatomy and Neurology, University of Toronto, Canada)

EXPLORER OF THE HUMAN BRAIN

The Life of
SANTIAGO RAMÓN Y CAJAL
1852-1932

by DOROTHY F. CANNON

WITH A HISTORY OF DR. CAJAL BY
CAROLINE SHERRINGTON



HENRY SCHUMAN NEW YORK

Copyright 1949 by Henry Schuman, Inc.

*Manufactured in the United States of America
by H Wolff Book Manufacturing Co*

Designed by Maurice Serle Kaplan

RECEIVED - 10/10/1964

Contents

	<i>Author's Preface</i>	vii
	<i>A Memoir of Dr Cajal by SIR CHARLES SHERRINGTON</i>	ix
i	<i>Patients and Partridges</i>	i
2	<i>Latin and the Dominies</i>	20
3	<i>The Marvelous Workmanship of Life</i>	40
4	<i>Cuban Interlude</i>	58
5	<i>"Poor Ramón Is Lost for Good"</i>	77
6	<i>The Bewitchment of the Infinitely Small</i>	102
7	<i>The Hard Bench of Analysis</i>	122
8	<i>The Ireful Stepmother</i>	153
9	<i>"Butterflies of the Soul"</i>	183
10	<i>The Human Cerebrum Stammers Some of its Secrets</i>	215
11	<i>Retirement and Last Years</i>	247
12	<i>Summation and Appraisal—by Way of Epilogue</i>	263
	<i>Selected Bibliography of Cajal's Works</i>	276
	<i>Bibliography of Sources</i>	279
	<i>Index</i>	295

Author's Preface

CAJAL'S STORY is a remarkable one—varied yet always engaging—and his personality is appealing from first to last. So much have I found this to be true that the many hours of research exacted by the preparation of his biography have been a pleasurable release from the more prosaic duties of recent years. If my own enjoyment in writing this book somehow manages to seep through its pages to the reader, he too, perhaps, will find this acquaintance with Cajal rewarding and the events of his life as interesting, amusing, and poignantly touching as they have seemed to me. Though I admire Don Santiago greatly, I have tried to keep this account from becoming a mere glorification of a great man. I have tried to present a true portrait of him as he was to those who knew him—in all his strength of character and of purpose, yet with none of his human weaknesses hidden from view. A bit disconcertingly, the weaknesses have proved to be but few and are for the most part endearing.

Throughout the chapters there are a number of quoted passages, translated from the Spanish of Cajal's own works chiefly, but also frequently from other Spanish writings, and from German, French, and Italian sources as well. Translation imposes its own limitations. Cervantes says somewhere in *Don Quixote* that translating from one language to another is like looking at a Flem-

Author's Preface

ish tapestry from the wrong side though the figures are visible, they are full of threads that obscure them and are not bright and smooth as they appear when seen from the right side. Although I know how much my English versions must lack of the full flavor of their foreign originals, I have made them as accurate and as easy and natural as my slender ability permitted. Perhaps the quotations from Cajal will, in spite of me, give some hint of his thought-provoking quality and of his gift for trenchant, vigorous expression.

My task in completing this book has been immeasurably lightened by the generous help of several unknown friends in Spain, the Argentine, England, and North America who have supplied me with first-hand materials that have added many revealing touches. Outstanding among these silent collaborators are Dr. Lu s Ram n y Cajal Fa an s, Cajal's only surviving son, Dr. Francisco Tello, Cajal's successor as director of the Instituto Cajal in Madrid, Dr. Fernando de Castro, Cajal's pupil, and today one of the leading figures in Spanish histology, and Dr. Mo ses Polak, friend of another of Cajal's pupils, Dr. P o del R o Horta a, and his follower as Director of the Laboratory of Histological and Histopathological Investigation of Buenos Aires.

I am deeply indebted to Sir Charles Scott Sherrington, leading British physiologist, for the admirable introduction he wrote for this book, and to Dr. Wilder Penfield, Director of the Montreal Neurological Institute, for his kind permission to quote from any of his writings. I am grateful, too, to Mr. Henry Schuman, publisher of this biography, for his encouragement and telling suggestions.

I hope this book will prove deserving of all the courtesies extended me in its preparation and, most of all, I hope, humbly, that it will prove deserving in some slight degree of its great subject.

A Memoir of Dr. Cajal

BY SIR CHARLES SHERRINGTON

THE SUBJECT of this Memoir was, besides much else, a man of outstanding personality. The excellent biographical portrait here furnished of him has brought back to me, vividly, a number of first-hand impressions received half a lifetime ago. Should this Memoir seem perhaps overladen with individual reminiscence, that, whether defect or not, is attributable to the conjunction of an exceptional human character with its unusually successful portrayal by the writer who follows me.

Santiago Ramón y Cajal spent his only visit to England—a visit of some two weeks' duration—as my house-guest. He had been little outside Spain. He was naïvely interested in what he saw of England. He was, for the time being, at a disadvantage conversationally, because he had no English, and what Spanish his hosts possessed did not suffice for more than a few halting sentences. His way out of this difficulty was to employ a sadly imperfect French, which he drove to its utmost limit or beyond. German he did not speak.

His rich voice compelled attention to whatever he said. The memory of that voice reminds me I have a privilege regarding him which, owing to lapse of time, must be becoming rare. My mind's-eye recalls him as he walked and talked and indeed as his outward appearance was, just at that stage of his career when he had re-

A Memoir of Dr Cajal

cently become, in his own line of science, an international figure. I see him a man perhaps a little below medium height—at least in London—broad-shouldered, spare, and strongly built. Of dark complexion, his olive-skinned face lit by brilliant eyes deep brown in color and of steady gaze. His hair almost black and closely cropped, trespassed low on a wide forehead. The strong face, completely shaven, had mobile, muscular lips. His hands as he sat and talked seemed to ask to be doing something. He was deliberate in his movements, but they were habitually energetic. He did not smoke, not even a cigarette. On being offered, inadvertently twice over, “something to smoke,” his reply was a vigorous, “*Mais la vie moderne est une chose déjà fort compliquée. Porter du tabac, des allumettes, etc., ça serait de la compliquer encore plus. Merci, non!*” His philosophy of life even in little things was never far to seek.

Two days after his arrival, as in the morning we sallied from the house-door into the street, he surprised me by the remark that England’s decadence was indeed obvious and that Spain regretted it. I asked him why he thought England decadent. He replied, “*Pas de fabriques pas d’usines*.” He told me that he had looked for them from the train window as he travelled from Calais, and there were none, and he now found very few in London itself. I said, “In this part of London there are not many, but in London taken as a whole there are many—too many!” I added, “Much business is done in London. Crowds of people come into London every morning for business and leave again in the late afternoon.” Feeling that he was still incredulous I asked if he would care to see them. Yes, he would. So next morning by 8.30 we were on London Bridge. The Bridge was flocked with people coming in from the Surrey side and a stream of wheeled traffic along with them. Cajal was deeply impressed, it was difficult to get him away. The next day, at his request, I sent him—I could not go myself—to watch the scene again.

He was strikingly simple in several ways. At dinner one evening
[x]

which but were served. The dish was new to him. He could not be persuaded to eat the tiny fish whole although he saw the rest of us doing so. He persisted in attempting to dissect out the backbone from each one, which was rather a trial to his hostess. We were delighted to find that at meals he would often manage to follow the general drift of talk at table, and that he did not let the language disability deter him from joining in. He would reinforce conversation with a little set speech, a short oration which developed its own peroration. This climax he would emphasize by a final dramatic gesture, for which his left hand had been preparing. If it had been busy crumbling the bread beside his dinner plate. It would gather the crumbs into a high pyramidal heap and then, to stress his closing words, sweep them with his cupped hand from the table to the carpet, accompanied by a challenging look round, and to the dismay of the maddening. This may have been a touch of rhetoric required at the famous Café Suizo in who ever the debating club Cajal was, I believe, prominent. Cajal was surprised to find so little café life in London, no outdoor café life at all.

He had more than once mentioned his wish to take from London some gifts for his wife and children, and we lunched at the Army and Navy Store that he might choose there some things for them. He was amazed at the extent and variety of the store. He spent three hours there but without making a purchase. Each time his fancy dictated a purchase, his Spanish love of a bargain impelled him to open a debate, partly in dumbshow, with the salesman or saleswoman with the object of lowering the price asked! He seemed prepared to devote the whole afternoon to such an attempt. I expect that where he and his wife did their shopping in Madrid, bargaining was still a customary procedure.

This simplicity of Cajal's ways and ideas is mentioned here because it illustrates how singular a mixture he presented of old time ways and ultra modern science. There was clearly an element of greatness in him. With peasant-like naïveté as to many of the ordi-

Cajal, and somewhat to Cajal's disgust—a conspectus of the Cajal conception, styling it the “neuron” theory. The term, although still current, is now less used than once Cajal himself clinched his new concepts by illustration with a number of admirable drawings from his own hand in hard black and white. A step amounting to genius, taken by him at an early stage, was his resort to material from the embryo (e.g., the chick) so as to escape the difficulty presented to his metallic methods by the developed myelin-sheath. As evidence of the breadth and sweep of his attitude toward the anatomy of nerve tracts in general, the following incident, which I give at first hand, is characteristic. I was helping him to choose some microscopic preparations from among those he had brought with him for the illustration of his Croonian Lecture at the Royal Society. He handed me a preparation showing nerve fibres descending to, and ending in, the spinal cord, and, as he did so, said, “Pyramidal tract.” “But,” said I, after a hesitation, “isn't this from the chick? Birds have not any pyramidal tract.” All he answered was, “Bien, c'est la même chose.” My remark, though correct, touched a detail too trivial for him to regard.

A trait very noticeable in him was that in describing what the microscope showed he spoke habitually as though it were a living scene. This was perhaps the more striking because not only were his preparations all dead and fixed, but they were to appearance roughly made and rudely treated—no cover-glass and as many as half a dozen tiny scraps of tissue set in one large blob of balsam and left to dry, the curved and sometimes slightly wrinkled surface of the balsam creating a difficulty for microphotography. He was an accomplished photographer but, so far as I know, he never practiced microphotography. Such scanty illustration as he vouchsafed for the preparations he demonstrated were a few slight, rapid sketches of points taken here and there—depicted, however, by a master's hand.

The intense anthropomorphism of his descriptions of what the preparations showed was at first startling to accept. He treated

the microscopic scene as though it were alive and were inhabited by beings which felt and did and hoped and tried even as we do. It was personification of natural forces as unlimited as that of Goethe's *Faust*, Part 2. A nerve-cell by its emergent fibre "groped to find another"! We must, if we would enter adequately into Cajal's thought in this field, suppose his entrance, through his microscope, into a world populated by tiny beings actuated by motives and strivings and satisfactions not very remotely different from our own. He would envisage the sperm-cells as activated by a sort of passionate urge in their rivalry for penetration into the ovum-cell. Listening to him I asked myself how far this capacity for anthropomorphizing might not contribute to his success as an investigator. I never met anyone else in whom it was so marked.

And there is yet another feature of Cajal's scientific verve which reading the accompanying biography has brought to mind insistently, and in it lies an element not without a pathos peculiar to itself. The "Cuban Interlude," so styled in this volume, lays bare to us Cajal's consuming love of country. This patriotism, at once passionate and patient, was at that epoch in Spain submerged in a general flood of contemporary frustration, especially as to all that pertained to distinction and achievement in the realm of natural science. A devastating pessimism reigned in Spain in those years, paralyzing modern Spain's grasp of and competence in science. A comment of Cajal's own countrymen on his early publications ran to the effect "Who is our Santiago to attempt to teach foreign savants?"

Cajal's own nature was far too strong for such despair. His faith in his country never faltered. His feeling was that if his country's powers had waned, it was for him and his contemporaries to give them renewal. Whence did he draw this inspiration? Not from his father, enough is told us to let us know that, although his father was remarkable and worthy and in a number of respects a forceful character, his struggles had choked out of him all trace of romance. As for Cajal himself, love of and devotion to Spain radi-

ated from him in his daily intercourse. Their utterance did not take the form of fond praise of all Spanish ways of life and modes of thought.

Often his reaction was regret at some defect he detected in Spain as contrasted with elsewhere. At the time when he was in London the "hansom cab" was the London gondola, it provoked from him the quaint comment, "The grey matter grows well under grey skies"—meaning by "grey matter" the sheet of the brain which anatomy connects with intellect, and by "grey skies" the sky of Britain as contrasted with that of Spain. The picturesque phrase was a favourite with him, it revealed how constantly his mind harped on the intellectual success and status of Spain. This solicitude for his country's repute deserves explicit mention here, it was perhaps the most powerful driving force in the make-up of his whole scientific character. It lifted him altogether above all personal vanity. His science was first and foremost an offering to Spain, a spiritual motive which added to the privilege of knowing the man.

In the intricate warp of the brain one can advance only step by step, and if one is to do so safely, the front trenches must be dug by men like Meynert, Golgi, Edinger, Flechsig, Kölliker, Forel, and the other great ones

But my youth of those days, quite confident and perhaps a little presumptuous, knew nothing of the wholesome fear of error, and I threw myself into the task with sure faith that in that dark thicket where so many explorers had been lost, I should capture, if not lions and tigers, at least some more modest game scorned by the great hunters

—RAMÓN Y CAJAL

I. Patients and Partridges

*Man wonders over the restless sea, the flowing water,
the sight of sky, and forgets that of all wonders man
himself is the most wonderful*

—SAINT AUGUSTINE

FROM a mischievous, fun-loving "problem" boy, the torment of his parents and his teachers, Santiago Ramón y Cajal became in his maturity Spain's most distinguished scientist and one of the pre-eminent men of science in the world. There is something of everything in his absorbing life story—comedy, irony, drama, heartbreak, failure, and triumphant success at the last.

Cajal's career was full of contrasts and contradictions. He had longed to be an artist but became a doctor, though at first he disliked medicine. He was an ardent patriot and once went overseas to fight for Spain but never saw a skirmish or a battlefield. Instead, he was destined to be a soldier of the mind, adding to his country's glory from the eyepiece of his microscope—when he finally managed to get one. Knowing his own temperament, he had chosen as his field the most unspectacular of the sciences—the study of the minute architecture of the nervous system, yet during his long lifetime he would often be showered with that very notoriety he shrank from. When he began his work he had only the most meager equipment, in later years a magnificent scientific institute would be built in his honor on a hill overlooking Madrid—though he would seldom set foot in it, it was far too grand for him!

Explorer of the Human Brain

His biography is rich in spiritual implications, showing at every turn how the perseverance of genius accomplishes its ends in spite of all the barriers time and race and country (not to mention human envy and weakness) so often manage to heap up in its way.

He was born humbly on May 1, 1852, in the little village of Petilla, which, by a queer geographical freak, though situated in Aragon belongs to the province of Navarre. Even to find Petilla on a map, let alone make one's way to it, is something of a task. In Cajal's day the stranger approached it mounted upon a mule led by someone familiar with the region. This is Cajal's description of his birthplace and the rugged country that surrounds it.

The panorama that strikes the eye from the railing of the church could not be more romantic and at the same time more gloomy and desolate. Rather than the home of happy and hardy peasants, it seems a place of punishment and expiation. A huge mountain, rocky and jagged, with steep, eroded slopes, fills the horizon with its great bulk. At the foot of this giant, a brook, rising in the hills near by, runs musically along the narrow valley floor beside the dangerous path that leads to the place. The sides and spur of the mountain, being the only arable land available to the people of Petilla, are streaked with many narrow fields laid out in terraces and laboriously defended against washouts from the torrential rains by stone buttresses and thick walls. Upon the peak, as if protecting the town from the cold north winds, great rocks shut off the sky and rise imposingly, like sharp sickles, a kind of cyclopean wall raised there by the force of some geological cataclysm. In the shelter of this natural defense, reinforced further by a feudal castle now in ruins, the humble houses of the village, between forty and sixty in number, are built upon rocks and separated by irregular streets, passage through which is hindered by crevices, stairs, and furrows cut in the rock by the violence of the rushing waters. As one looks at these miserable homes, he feels only sadness—not a flowerpot in the windows, not the least adornment on the housefronts, nothing to indicate the slightest feeling for beauty or the slightest aspiration toward convenience or comfort.

It is easy to see that the country people who live in these wretched

dwellings are condemned to a hard existence with no other interest than to get by rigorous labor the most frugal daily nourishment . . .

And the great majority of the people in my village do live so, with trifling differences. Their ignorance is the result of their poverty. For them the intellectual pleasures that make life agreeable and compensate us for its brevity do not exist.

CATAL'S PARENTS

TO THIS MELANCHOLY VILLAGE the uncertainties of the medical profession had taken Justo Ramón Casasús¹ some years before the birth of Santiago, his eldest child. Don Justo was a man of extraordinary character. He had been born the youngest son of modest farmers in Larrés, a village in the province of Huesca. Upon the death of his parents, his older brothers inherited the family farm, and when he was still very young, he had to leave home to make his own way in the world. As was the custom in those days, he apprenticed himself to a surgeon of Javierre de Latre, a village on the bank of the Gillego River not far from Anzánigo. He spent almost ten years with his master, becoming a barber and blood letter, quite in the tradition of the Spanish picaresque hero Gil Blas, though on a much higher level so far as the real skill and learning of his teacher were concerned. In fact, his master was famous for his brilliant cures. He not only inspired his pupil by his example but also gave him the free use of his library of books on surgery. At this point Don Justo might have stifled his ambition by becoming a male nurse. But that was not enough for him. His one desire now was to become a fully trained doctor of medicine.

¹ Spanish surnames are commonly made up of the surname of the father, followed by the surname of the mother before her marriage. These are often, but not always, connected by "y," which means "and." Ramón Casasús, Ramón y Cajal. (Sometimes, for brevity, only the second of the compound surname is used—e.g., "Cajal"—when no given name or title precedes it.)

Explorer of the Human Brain

The time came when, if he were to begin to attain this goal, he would have to break with his present life and get further training by some means or other. One day, when he was already nearing twenty-two, he shocked his master by asking for his pay and resigning from his position. He went on foot the long way to Barcelona, where, after several days of hunger and pounding the pavements, he found a barbershop whose owner would let him work for him while attending courses at the university. With no other money than his earnings at the barbershop, he completed his studies and at last had in his hands the diploma of a second-class surgeon, this permitted him to perform minor operations but not to practice as a full-fledged physician. "There," his son wrote many years later, "in his quiet and obscure struggle for spiritual and physical nourishment, breathing that atmosphere of indifference and coldness that surrounds the talent of the unprotected poor, my father learned that fear of poverty and that exaggerated worship of utilitarian science that later, as a result of the mental reaction of his sons, were to cause him and us so much trouble."

Don Justo soon won a reputation for competence and integrity throughout upper Aragon and Navarre, and his modest practice brought him an increasing, if never too abundant, income. Living in remote Petilla and passing through the wooded countryside on his rounds each day, he developed a love of the chase. With that earnestness that he put into everything, he became an accomplished hunter of rabbits and partridges. It was not long, his son says, before he had monopolized both the scalpel and the gun throughout the whole region. So, after two years in Petilla, with the returns from the patients and the partridges, he was able to establish a home for the girl from his home town whom he had loved since childhood. It was not until some years later, when he was married and already the father of four children, that he finally earned, through hard study and rigorous economy, the coveted degree of doctor of medicine.

Cajal's mother, Doña Antonia, was a lovely highland girl. Her

son bemoans the fact that not a scrap of her beauty was handed down to any of her children. They were all exact replicas of their father. If young Santiago was cheated in regard to inheritance of his mother's handsomeness of face and gentleness of nature, he was not too badly used by fortune, for his portraits and photographs show a face of aristocratic refinement, with sensitiveness and strength of purpose in it, and something of the elegance of the Spanish grandee.

From his father he inherited qualities of greater importance to his lifework—a belief in strenuous effort and its power to remake the world, the ambition to make a contribution of real worth, and the will to spare no sacrifice in so doing and to admit of no detours in this stony road to achievement. He lacked, he says, his father's extraordinary memory, which had enabled him to memorize without effort whole volumes of pathology. He did not lack his father's determination and his possession of its match made for bitter conflicts between them throughout his boyhood.

CHILDHOOD AND EDUCATION

SHORTLY AFTER SANTIAGO'S BIRTH, his family moved back to Larrés, his parents' native village. Santiago kept only hazy memories of the years spent here—mostly of his grandfather's weaving shop, where he loved to tangle up threads and shuttles. The Cajals' second son, Pedro, was born in Larrés. Santiago's first clear recollections were of the much larger town of Luna, near Monlora, to which his parents removed shortly afterward. Soon after this, Don Justo, following the vicissitudes of a struggling doctor's lot, moved his family to Valpalmas, three leagues away. They stayed in Valpalmas from 1856 to 1860. Here two little girls—Paula and Jorja—were born.

When Santiago was four, he entered the district school of Valpalmas. But his real education came from his father in the early

Explorer of the Human Brain

years Don Justo was a born, though inexorable, teacher and could no more have given up the chance to instruct his children than he could have contented himself with the humble duties meted out by his old master of Javierre de Latre. His son says of him, with the wryness he so often uses when speaking of his father, that he was (as Socrates boasted of himself) an "excellent accoucheur of intellects." In later years Cajal himself was to become that, in large measure. He says of this predisposition in his father:

There is in the function of the teacher something of the arrogant satisfaction of the breaker of colts, but there enters also the kindly curiosity of the gardener who eagerly awaits the spring to find out the color of the flower he has sown and to test the success of his methods of cultivation. I hold, for my part, that to develop an embryonic understanding is to attain the most lofty and noble paternity, it is as if to correct and perfect the work of Nature. To construct original brains, that is the great triumph of the teacher.

Santiago was never to forget the zeal Don Justo put into teaching him French. The lessons took place in an abandoned shepherd's cave, and subject matter and setting became so intertwined in his young mind that for the rest of his life whenever his eyes fell on a copy of Fénelon's *Télémaque* he would see the old cave again with its dark recesses and winding corridors.

At six he could read and write and had some notions of French, geography, and arithmetic. As a result of this promising beginning, he became the family secretary, and when his father left home shortly after to go to Madrid to complete his work for his degree, little Santiago was entrusted with the task of keeping him posted by letter on the local gossip and the family news.

In view of all this precocity, his parents expected something unusual of him. They were long to be disappointed, for he turned out to be a normal, healthy, mischievous boy, a lover of the outdoors and skilled in games and sports. He had boundless curiosity about the ways of the natural world and an inborn sensitiveness to natural beauty. Coupled with this were a love of solitude and a

shyness and awkwardness with older people. He would spend whole days wandering over the hill and through the ravines, filling his eyes with what he calls "Nature's gaudy festivals"; he would lie flat on his stomach for hours studying the life of the insects. He loved all animals, but especially birds, and took pleasure in taking care of their nests, making pet of them. He made egg collections, which his studies grew to spectacular proportions, these came to an untimely end one summer—ruined by the August Ice.

Since Nature had revealed herself to Santiago only as the kind mother the ice and the Cable. Soon he was to show herself in another mood. An event of this period left an indelible stamp on a boy's life, and it gave a more sober coloring to his earlier on life. He came to realize that man lives in a universal bond, a natural law that is indifferent to him and to his petty loves, joys, and dreams.

One day in April, he was struck by lightning. The children had been saying their daily prayer. At the words, "Lord, deliver us from evil," the whole school building, freezing the blood in their veins. The air was filled with dust and fragments of plaster and the head smell of sulfur spread through the room. Half-blinded, falling over one another and over the debris from walls and ceiling the children struggled to escape. One child found the door closed and the others stumbled out after him. Some neighboring women rescued them, wiped off the plaster dust that made them look like terror-stricken little ghosts, and bandaged their cuts. Just at that moment someone pointed to a black figure caught in the ruine of the church belfry, its head hanging over the wall. It was the parish priest, who had tried to warn the people of the danger by tolling the church bell. His clothing had caught on fire and there was a great gash in his neck, from which he died a few days later.

The bolt had hit the church tower, melting the bell and striking the priest. By a caprice, it then entered the schoolhouse

Explorer of the Human Brain

through a window, shattered the ceiling, glanced off the teacher, destroyed a picture of the Saviour, and disappeared through a mouse hole in the wall

Cajal analyzes his reaction to this strange tragedy

For the child, Nature is a perpetual marvel—the scientific conception of law penetrates the child brain very slowly. This seeming capriciousness in Nature does not disquiet the child. That is prevented by the profound optimism of all beginning life and especially by the certainty acquired from the teaching of the Catechism that there exists on high a good God who watches over the working of the great cosmic mechanism and keeps order among its elements. Parents and teachers have also told him that the Psychological Principle of the universe is, moreover, a tender father and a sublime artist. That in His infinite power He has ingeniously adapted the changes of the seasons to the necessities of life, and descending from the highest heaven, deigns to compose and preserve superb pictures for the pleasure of mankind: the sky with its roseate clouds, the fields of springtime sown with poppies and dotted with butterflies, the dark night spangled with stars, the trees and the vines heavy with fruit.

But here, all at once, this beautiful conception which I, like all other children, had accepted was rudely shaken. The bright palette of the artist darkened, the idyll became tragedy. My mind floated in a sea of confusion, and anxious questions came thick and fast, with no satisfactory answer.

The second momentous event of Santiago's childhood was the eclipse of the sun in 1860. It had, of course, been announced in the newspapers and was eagerly awaited by the townspeople, who, dark glasses in hand, thronged the hilltops for the best possible view of it. Don Justo had told his children all about eclipses, but in Santiago's now skeptical mind a doubt still lingered. Could human intelligence, which had not foreseen the striking of church and school by lightning, predict events taking place millions of miles away from the earth? Yet he found that all went off with admirable precision. He was as much impressed by the fear engen-

dered in all sentient life by this upset in the regular rhythm of light and darkness as by the canny calculations of the astronomers, which he now had to accept without mental reservations. He came to see that, helpless though man is before the forces of Nature, he possesses in science an instrument of foresight and of power.

Shortly after this, a seemingly great political event was the occasion of an outburst of national patriotism, arousing the first stirrings in Santiago of that burning love of country that was to be a driving force throughout his life. For the first time in many humiliating years, the banner of Spain floated over a foreign city—Tetuán, later to become the capital of the Spanish zone of Morocco. In the Moroccan war of 1859-60 the native chief, Muley el Abbas, was defeated and Tetuán was taken with much bloodshed. The noted Spanish generals Juan Prim and Leopoldo O'Donnell were the men of the hour. The festivities organized by the officials of Valpalmas in honor of these generals and of the Spanish soldiers they had led to victory were grandiose for that simple town. A band imported for the occasion played—scratchily—marches, one-steps, and *jotas*, and there was dancing in the streets. A roaring bonfire in the public square roasted sheep and fowl for everybody. Savory chunks of meat were passed round and leather bottles of wine went swiftly from hand to hand.

THE REIGN OF ISABEL II

WHAT WAS THE BACKGROUND of all this celebrating throughout Spain and how important, really, was the event it commemorated to the main current of Spanish history? Morocco had long been the arch enemy of Spain as well as the legendary foe of Christianity. From the days of the Barbary pirates it had been a plague and a thorn in the flesh, lying there so close across the Strait of Gibraltar. It had been easy for the generals—the real rulers of Spain in

this period—hiding behind the none too clean skirts of Isabel II, to play upon this age-long hate when it served their purpose to distract public attention from disastrous affairs at home by undertaking an expansionist campaign in Africa

General O'Dónnell had been prominent in the temporarily successful Liberal revolution of 1854, although for all his quasi-liberal leanings he was a staunch supporter of the reigning Bourbon house. He had won a name for himself through his foreign policy, which had involved such varied activities as his refusal to sell Cuba to the United States, his plan to help France in her ill-advised and ill-fated attempt to set up Maximilian and Carlotta as rulers of Mexico, and now this war in Morocco. The chief result of the Moroccan adventure, as it turned out, was to make a popular hero of General Prim, a far more liberal man than O'Dónnell and one less devoted to the Bourbons.

Prim was the third of the triumvirate of generals then ruling Spain. The other two were O'Dónnell and the tyrannical General Ramón Narváez, the queen's mainstay. Narváez controlled the army and, when occasion demanded, he would strike out at the growing liberalism of the time with the weapons of exile or swift execution for those who were "tainted" by it. The power of this Spanish Robespierre was so great, in fact, that he had managed to save Spain from the revolutionary storms that had shaken or overthrown many European thrones in 1848.

These three men explain the era which was the historical setting of Santiago Ramón y Cajal's childhood. The character of the queen explains it too. Isabel was the elder daughter of Ferdinand VII and of his fourth wife, María Cristina, a Bourbon of Naples and his niece. When Isabel was three years old the king died and her mother became regent, directing the policies of Spain from 1833 until the accession of her daughter in 1840, when Isabel was only ten. During her regency the queen mother had been the subject of much salacious gossip as the result of her secret marriage to her lover, Don Fernando Muñoz, a low-born corporal whose father

had once kept a small tobacco shop. By Muñoz María Cristina had several children, whose births she had naïvely tried to conceal from her people.

Isabel was married while still very young to a man she detested with all her passionate being—her first cousin, Don Francisco de Asis. This marriage was the outcome of an international intrigue of vast proportions, the chief proponents being Queen Victoria of England and Louis Philippe and Marie Amélie of France. In spite of the cousins' mutual repugnance, Don Francisco was the only candidate found to be acceptable to the royalty of Europe, to whom it mattered very much at this critical juncture that there be order and stability in Spain. Stringent methods had been used to force the strong-willed Spanish queen into it. Some say her consent was secured after a wild supper party, others say that she was bullied into it by her stepfather, Muñoz. By whatever means this ill-matched pair was brought together, it was decided that Isabel should be married on her birthday and that her younger sister, Luisa Fernanda, should on the same day marry the Duke of Montpensier, son of Louis Philippe and Marie Amélie. This marriage constituted a strategic victory for France, for if Isabel had no children (and it was rumored that Francisco was something of a weakling), her sister or her sister's children would inherit the throne of Spain. Such was the unsavory affair of the "Spanish marriages."

Madrid welcomed the young queen and her consort with enthusiasm. But Francisco was no success as a husband for Isabel, and she promptly realized what an unhappy situation she had been forced or tricked into on that memorable midnight when she had given her consent. The marriage was a mockery. Very soon Isabel's life became a long series of adventures, some carried on openly, others more discreetly hidden from the public eye. Don Francisco took no part in her gay life. It was easy for her to find more congenial company. One of her cavaliers was the dashing young army officer Don Francisco Serrano. Her mother, María

Explorer of the Human Brain

Cristina, disapproving of the dissipation she saw everywhere about her, retired to France. Meanwhile the Spanish Liberals too were disgusted with the course events were taking and plotted revolution, but only sporadic, abortive uprisings broke out, and these were quickly dealt with.

Eventually the inevitable separation between Isabel and her husband took place and there were rumors that the queen was carrying on a love affair with Serrano. María Cristina wrote touchingly from France to persuade her daughter to return to her husband for the good of the country and the security of the Spanish throne. Emissaries were dispatched to Don Francisco de Asis with the same pleas. He responded to them with a certain dignity and reasonableness, and things were somehow patched up. Then, contrary to the expectations in some quarters, Isabel did have a family after all. The first of her children died three days after he was born, it was said he had been strangled. The second child was the Infanta Isabel. Six years later, when her son, Alfonso, Prince of Asturias, was born, there was national rejoicing and for a time a resurgence of Isabel's former popularity. Her favorite at this time was the officer Puig Moltó, who, upon the birth of the child (said to be his son), was rushed into exile. Later, two daughters were born, and gossip raged over their births as furiously as it had over the births of María Cristina's children born during her secret marriage to Muñoz. But by this time Isabel had been involved in so many scandals that her mother's amours paled into insipidity beside them.

Though Isabel had graciousness of manner and regal imperiousness, she had no capacity to govern. She was constantly swayed in her judgments by her ever changing lovers, and ministries rose and fell at her whim. Such was the temper of her reign—essentially a military dictatorship—with immorality, corruption, and reaction deeply entrenched in it. Upheavals were soon to submerge Spain in a tearing avalanche. But for a time the generals staved them off by just such decoys as the Moroccan war. The victory

at Tetuan then was not of lasting importance to the main course of events in Spain, though it did awaken a fervent patriotism in the breast of Santiago Ramon, a Castilian aged eight.

ADVENTURES IN AVERBE

WHEN Santiago was still eight years old, the family removed from Valpurga to Averbe, a town known for its wines, located on the road from Hueca to Jerez, not far from the first spur of the Argentine Pyrenees. A high escarpment with twin peaks towers above the town, crowned with the ruins of a feudal castle. At its foot Averbe spread out around two large squares, famous for the exhibitions held on them, and separated from each other by a mansion that had once belonged to the marquises of Averbe. Beyond were the humbler houses of the town people.

Upon Santiago's arrival in Averbe he was thoroughly beaten by the town boys for being a stranger that he was—to put in an appearance on one of the squares. Perhaps for all his open air look and his modest dress he seemed a dandy to these rough children. In any case they strongly objected to his pure Castilian speech, which they looked upon as a most disgusting affectation, for Averbe had a freshish dialect—a mixture of French, Castilian, and Catalan, with a dash of archaic Aragonese. The total effect of this mixture was to make one feel as though he had unexpectedly parachuted into Portugal. In time, Santiago was to find it wise to accommodate himself to the local jargon, and in time, too, he found his place among the rascallions of Averbe, becoming a bit of a town character himself. Soon he was expert in their games, races, and jumping contests.

All was not such innocence, however. There was a certain amount of stone throwing, pillaging, and raiding apple and perch orchards. Not that there wasn't plenty of fruit to be had at home—the doctor's house particularly was full of gifts of vegetables and

fruit from grateful though cash-poor patients But stolen fruit is always sweeter Scratch a child, Cajal says in effect, and you find an anarchist

Santiago eventually became the acknowledged leader of the gang He learned to handle the cudgel, the arrow, and the sling-shot with equally deadly accuracy Such talents could not be left unused He got for his partners the finest fruits to be stolen anywhere round about, sparing the gardens of neither priest nor mayor It was he who organized the mischief clearly called for when an old man, for example, or a much-married widow ventured once again into the whirlpool of matrimony, it was he who made the flutes, whistles, and cowbells demanded by the occasion He became, in fact, a famous flute-maker and also maker of the slings needed for stone-throwing, using the leather from the upper part of his boots, if need be (This was not a recourse popular with his parents, but leather was scarce) He made the cuirasses, the helmets, and the arrows needed for organized warfare He became an expert arrow-maker and built up fair-weather friendships with shoemakers' apprentices for the sole purpose of gaining access to his raw materials—the broken awls These arrows were occasionally used for the less romantic, utilitarian purpose of shooting birds and rabbits

The cost of these enterprises was endless whippings No crime was committed of which Santiago was not accused—either he had just done it or he was going to He would try to be good after chastisement at home or at the hands of the neighbors, but after a time the devil would rise up in him and he would be in disgrace again

It was about this time, surprisingly, that his artistic urges began to show themselves He was forever making sketches on scraps of paper, on the walls, on the margins of his schoolbooks Since this caused his father unending annoyance, Santiago could not draw openly at home, so he would go off into the country, sit on the bank of a stream or at the edge of a road, and sketch everything

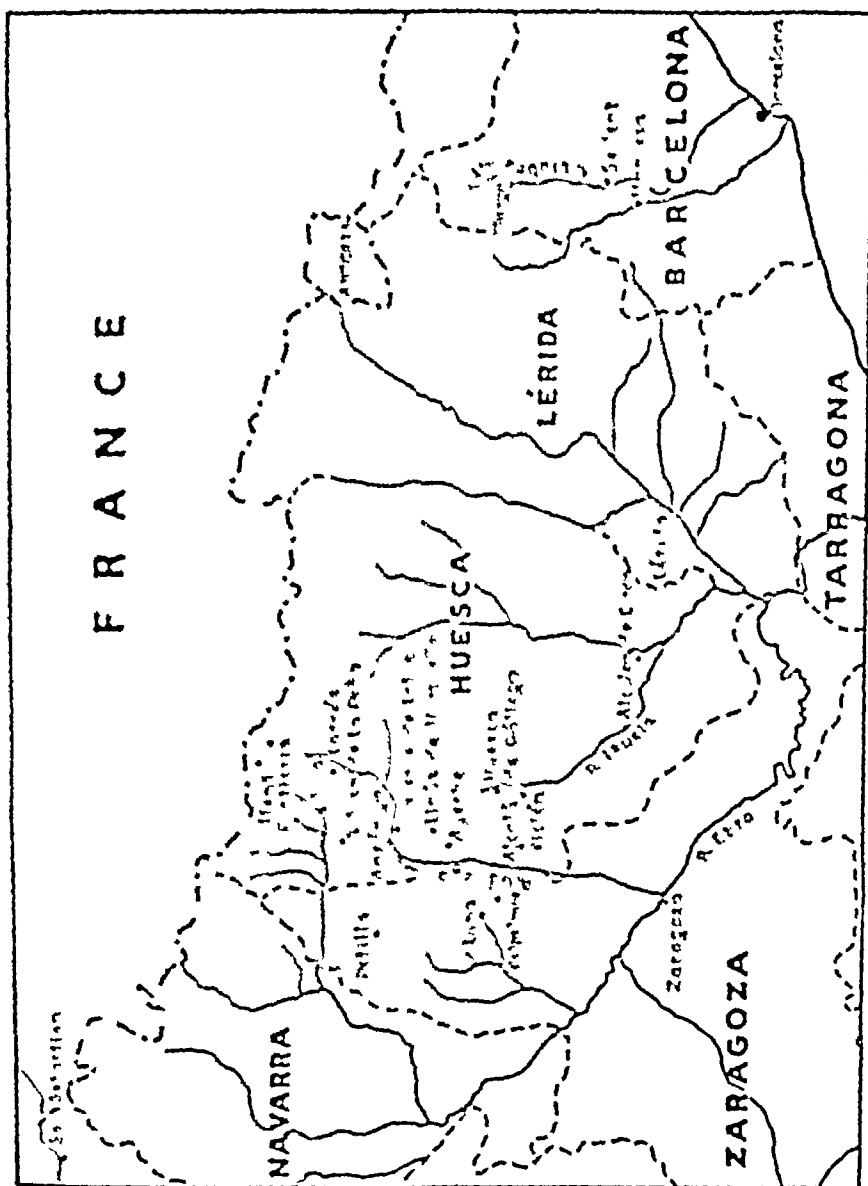


FIG. 1 — NORTHEASTERN SPAIN

that hove into view—farmers with their carts, horses, cats, dogs. He later graduated to painting, getting his pigments by scraping the paint from the walls of buildings or by soaking the bright-colored booklets cigarette papers came in. For brushes he used bits of paper rolled into wads. His artistic leanings intensified his natural shyness and solitariness, for he needed privacy to manufacture the materials for this forbidden pastime.

Don Justo had no use for art or culture of a purely ornamental kind. This side of his son enraged him. Man to him was solely a machine made to acquire knowledge and turn it to useful ends. A boy should be trained young, and in the most direct and practical way, to meet the responsibilities of life. Rigid economy was the order of the household, even beyond the point where it was necessary or even desirable. This exaggerated thrift on Don Justo's part was understandable in the light of his own early struggles, but it tended to make home too drab a place, too lacking in normal pleasures and in those wholesome little extravagances that might now and then have added savor to the mother's hard-working life and to the children's, and would have given momentary respite from the stringent discipline imposed upon them all. But there was to be no art, music, novel-reading, or theater-going for the Cajals.

It was not surprising that a sensitive, creative boy like Santiago would eventually react against so gloomy and inflexible a background.

Certainly without the mysterious attractiveness of forbidden fruit the wings of my imagination would have spread, but they perhaps would not have reached the overdevelopment that they attained. Dissatisfied with the world around me, I took refuge within myself. In the theater of my feverish imagination I substituted for the common beings who work and economize ideal people with no other occupation than the serene contemplation of youth and beauty. Translating my dreams to paper, with my pencil as a magic wand, I constructed a world according to my own fancy, a world that contained all those things that

nourished my dreams. Dantesque countryside, pleasant, smiling valleys, devastating wars. Greek and Roman heroes, the great events of history, all flowed from my restless pencil, which paid little attention at this period to common scenes, to ordinary nature, or to the activities of everyday life. My specialty was the terrifying happenings of war, and so one moment I covered a wall with sailing ships, with sailors rescued on planks, with ancient heroes covered with shining harness and protected by plumed helmets, with catapults, battlements, moats, horses and riders. Needless to say, being driven from imagination, these scenes did not pass beyond the class of pretentious and grotesque scribbles or lifeless manikins.

Sometimes Santiago turned from warriors to saints, preferring the active ones to the contemplatives. One of the "portraits" of the Apostle Saint James (his patron saint) that he drew on paper and embellished with such colors as he was able to concoct became a *cas célèbre*. His father had grown weary of denying him paints and brushes only to have him doing his art work all over the neighborhood, so he decided to settle this thing once for all. There was no one in Ayerbe who could tell him whether his son had talent or not, but when a certain plasterer and decorator one day descended upon them from another town, Don Justo prepared for a showdown.

Santiago exhibited his Saint James. The plasterer surveyed it gloomily. Then: "What a drub! No proportion! Draperies all wrong. This child will never be an artist."

"Doesn't he show any aptitude at all?" This from Don Justo, offended pride and relief mingling in his tone.

"None, *amigo*." Then to Santiago, who was struck dumb by this inexorable judgment: "Look at the large hands on your apostle. Like a glovemaker's samples! Look at the shortness of the body. And the horse! Looks as if it had been taken from a merry-go-round."

Santiago tried to blurt out something. In later years he realized that his sketches would have been considered quite creditable

Explorer of the Human Brain

examples of modern painting, but in those years classicism was in its heyday His father's silence told him all was lost

At a family meeting it was decided that Santiago should henceforth renounce art and espouse medicine Efforts to confiscate his pencils and charcoal amounted now to persecution and he took to devious ways of salvaging them Don Justo's war on his son's true vocation went on for twelve years He won in the end The palette gave way to the bag of surgical instruments, the brush to the scalpel

During these years Santiago went to school in Ayerbe—often playing truant On such occasions he used to explore the ruins of the castle overlooking the town or hunt for magpies' nests in the forest of live oaks Once he was bitten by rats marauding a magpie's nest and eating the eggs

One day, wishing to examine an eagle's nest at close range, he climbed down a series of ledges over a cliff to where he could see the naked eaglets staring at him Suddenly he heard the screams of the returning mother eagle and tried to escape from his ledge But the narrow shelf of rock to which he had jumped down from above jutted out from a smooth, almost perpendicular wall He had to stay there for hours in the burning sun, terrified of falling and with no hope of help At last he got the idea of widening the cracks in the soft rock of the wall with his penknife, making them large enough to give him a momentary foothold by which he climbed up to safety

When Don Justo learned of such escapades as this one, he would administer a sound thrashing and would reprove his wife for too much softness toward her sons Pedro got his share of thrashings too, for he was quickly learning to follow in his brother's footsteps These floggings were of no inconsequential nature—they were with whip or cudgels Even the threat of one once caused the boys to run away from home They stayed away for several days, living in the woods until one night their father found them sleeping in a limekiln He woke them up, tied them arm to arm, and

matched them home through the public square to be jeered at by the townsfolk.

The beatings eventually had some effect. At least they brought about sullen attendance at school. But, says Santiago,

All that was accomplished was to change the scene of our misdeeds. The stretches of the countryside were replaced by caricatures of the master. The battle in the open air were changed to skirmishes among the benches in which paper pellets, cabbage stalks, haws, chick peas, and kidney beans served as missile. And for lack of paper for drawings I used the wide margins of the Catechism, filling them with risqué ornamentation, furniture, latches, and puppets, some related to the pious text, other irrelevant and profane.

When the schoolmaster found Santiago's caricatures and his chatter with his schoolfellows too much to bear, he would lock him up in a dark room—a room that it was almost underground and overrun with mice. Here in quiet seclusion Santiago would plan the next day's mischief.

While in his dungeon one day he made a discovery—one he thought to be new. The shuttered window of the room faced the sunshiny public square. A slender beam of light coming through it projected on the ceiling upside down and in natural colors, the people and the animals passing outside. When the hole in the window was widened, the image became faint, when narrowed, it was sharper. In a rough way Santiago formulated in his mind the principle of the *camera obscura* discovered long before by the Italian artist and scientist Leonardo da Vinci, concluding that the rays of light, because of their absolute straightness, paint an image of their source whenever they are made to pass through a small hole into a dark chamber. He began to think of physics as the science of marvels, and amused himself in his prison by tracing on paper these bright images which had come so opportunely to comfort his solitude.

2. *Latin and the Dominies*

To frighten an entire class is easier than to teach one boy properly for the latter is and always must be a task as serious as it is honorable

—ERASMUS

IN 1861, when Santiago was nearly ten years old, the first real contest of wills between him and his father was battled out over the question of his schooling. Don Justo won. Santiago's talent for painting was to be brushed aside. He was to be shipped off to Jaca to study for his bachelor's degree¹ at a college run by Esculapian² fathers, who were famous both for the excellence of their Latin instruction and for their skill in breaking the high spirits of rebellious sons. Santiago had begged to be sent to Huesca or to Zaragoza to art school. He disliked the idea of studying medicine and had but little love of Latin. But his father had no use for artists—to him they were dilettantes, wastrels, unwilling to do honest work, and destined to end up as poverty-stricken ne'er-do-wells. He looked upon his son's liking for art as a sort of developmental defect which he was bound, as a good parent, to beat well out of him. As part of this campaign, he filled Santiago's ears with tales of artists he had known who had ended as failures, of "historical painters with too much history," of writers who never got beyond being small-town

¹ Requiring the equivalent of two years' undergraduate work in an American college or university. The curriculum at this time included the history of Spain, Latin and Greek, algebra, and trigonometry.

² Catholic order founded at Rome in 1614 and devoted to the education of children.

Explorer of the Human Brain

spare the rod The friars reassured him on this point and led him shortly to Father Jacinto, professor of elementary Latin, a giant with fists of steel, champion youth-breaker of the community Santiago passed the entrance examination creditably and his father, well pleased with his negotiations, returned to his patients in Ayerbe

Uncle Juan lived with his one remaining son, Timoteo, then an apprentice in a chocolate factory The home was left to the ministrations of a housekeeper, an all-too-economical cook who provided them with little meat but plenty of cabbage, turnips, and cornmeal porridge On special occasions, bits of pork appeared in the cornmeal When hunger gnawed too sharply, there were apples to be had and potatoes roasted in their skins

On this diet Santiago soon became as thin as a toothpick His intellect also failed to improve and the friars could not pound much Latin into him But while his intellect shriveled, his imagination spread its wings His interest in art burst out all over again and the margins of his books bloomed with landscapes, portraits of historical personages, and caricatures of his professors These were much admired by his classmates, and his schoolbooks, he says, were more passed to and fro than the rolling pin of a cookie-maker

This attempt at educating Santiago was a melancholy fiasco The friars lost the battle Even though reinforcing their precepts with the strap, the dominies could not teach him anything He loathed their rote-memory methods—for thinking heads they substituted stored heads In every way the school at Jaca proved to be another version of Dickens' Dotheboys Hall There was no camaraderie, not even the semblance of friendship, between pupils and faculty In the later years of the curriculum, the school did provide some teachers who were understanding, but the younger boys did not encounter these The rough-hewing of the beginners was done by the harshest masters, following the principle (so Cajal said later) of grinding the knife first with the coarsest whetstone Father Jacinto was the worst—a huge bully with a thunderous

voice The forty children in his Latin course, still homesick for their mothers, spent the class hour so filled with dread of him that it blotted out what little knowledge they had managed to scabble together Weak memories were strengthened with the cat-o'-nine-tails This treatment destroyed the boys' self-respect and personal dignity and crushed any hope they still might have of doing better, since they were constantly told they were stupid, they came to believe it and made no further effort to learn

The beauty of the countryside about Jaca gave Santiago some comfort The city too, with its old cathedral and its towers and battlements, had magic for him He loved to stroll along the ancient city wall, high above the rooftops, and to wander on the river bank, recreating in his imagination events in Spanish history that had had this region as their setting long ago He would wonder as he rambled about Jaca what lay beyond those silent Pyrenees, his wanderlust was stirred and his hunger whetted for new horizons. Once he tried to climb to the summit of a mountain—even got to the foot of the Col de Ladrones (Robbers' Pass)—but had not time before dusk fell to finish this exploit And once he reached the first ramparts of Uruel, but had to abandon this too and go back home hungry and footsore

The days dragged by at school Since by now the boy was so calloused by thrashings that they no longer "took," Father Jacinto changed his tactics One of the "teacher's pets" in the Latin class was commissioned to keep a record of Santiago's failures and misdeeds, each of which had to be paid for by a fast a day He would be locked up in the schoolroom when lessons were over and could have nothing to eat until night His criminal record eventually grew so long that he regularly ate only once in twenty-four hours

Knowing he was foredoomed to failure, he made no attempt to extricate himself, and his "penance" continued to pile up unremittingly One day he found a way to spring the lock of his prison, using a pencil as a lever, and for some time after that he managed to steal home for a midday meal But he was at last found out and,

Explorer of the Human Brain

as the ultimate in disgrace, he was decked out as a *rey de gallos*, or king of cocks, garbed in a motley robe and crowned with a head-dress of feathers, like an Indian chief. Blows were added to this ignominy, but, worse still, the lock of the schoolroom door was changed and escape by this route was blocked from that time forth.

Once the friars forgot to free him at night and he lay on a bench, shivering, hungry, and thirsty until the class assembled the next day. He determined to find a way out so that this would not happen a second time, and he found one. The schoolroom was on the first floor overlooking the garden, so he made a sort of stairway with spikes in the wall below one of its windows. He could climb down to the top of an arbor that touched the wall, and from there could clamber to the garden and make his getaway. He took to eating at noon again, being careful this time to be back in his prison before his absence was detected. But this trick, too, was soon discovered. Other prisoners learned about the secret stairway, used the spikes with less agility than he, and were caught in the act. To save their own skins they told who had driven the spikes into the wall. The friars summoned Santiago and threatened to expel him from the school. Terrified at the thought of Don Justo's anger if they should carry out their threat, he wrote a letter to his father telling him the whole story and begging him to intercede. Though Don Justo was furious at his son, he did plead for him, asking the friars to be lenient in view of the debilitated state of Santiago's health. The affair blew over in time and Santiago completed his first year's work.

SUMMER MISCHIEF

ALTHOUGH HE RETURNED HOME for the summer holidays in very bad shape physically as a result of the rigors of these months at Jaca, it was not long before the fresh air of Ayerbe, his mother's

[24]

good cooking, and the fun of being with the old group of pranksters again brought back Santiago's natural robustness and cheerfulness. The summer mischief began directly and this year it was chiefly military. Santiago made a cannon out of a log he found at home by boring a hole through its length and reinforcing this priming hole with a tight-fitting tube of tin from an old oil can. He and his colleagues were immensely proud of this cannon and to try it out hoisted it up on the Cajal orchard wall. The target for the day was the new gate of a neighboring garden. The gun was loaded carefully—first a handful of powder, then a fat wad of paper, then tacks and cobblestones. In the priming hole, now filled with powder, a fuse of touchwood was inserted. This was lighted by a match attached to a piece of wire, whereupon the boys fled to a safe distance to await the outcome. The report was ear-splitting, but, to everyone's surprise, the cannon performed its function properly without blowing up itself. Above the broad hole it had made in the gate, however, the livid face of the neighbor soon appeared. The soldiers took to their heels, vanishing in all directions, abandoning their artillery. Their flight was aided by the thoroughly battered condition of the gate, which prevented the neighbor from getting it open for a while, though some of the stones he hurled at them as they fled did hit their mark.

Events now took a headlong course. The neighbor complained to the mayor, who sent a constable to put eleven-year-old Santiago in jail. Don Justo thought his son had this coming to him, hoped that it would teach him self-discipline, and requested that he be deprived of even the ordinary prison fare while serving out his sentence. It was a dreary moment when Santiago heard the creaking of the bolt that shut him in his cell and the footsteps of his jailer going farther and farther away. Soon he heard a clamor outside his window—a swarm of women and children had come to jeer at him through the grating. Enraged at this, he threatened them with a stone he had found in his prison and they went

Explorer of the Human Brain

away, leaving him sullen with resentment. At last he roused from this to inspect his cell. Its sole "furniture" was a pallet of moldy straw crawling with fleas, spiders, bedbugs, and lice. He went as far away from it as he could, stretched out on a relatively clean bit of flagstone on the floor, and slept most of the three or four days he had to stay there. His mother managed to get food to him by stealth, for Don Justo would not rescind his order that the boy be kept on bread and water.

This severe punishment did not reform him. He and his friends made another cannon (this one did blow up) and tried other experiments in ballistics, as, for example, loading a bronze pipe with powder to the mouth and setting it off. The pipe blew up in Santiago's face and might have cost him his sight, but it merely caused an inflammation in one eye, and left a permanent scar on the iris.

AT SCHOOL IN HUESCA

BY THE TIME the summer was over, Don Justo had given up all hope that the Esculapians would ever make a scholar of Santiago. So he transferred him to a different type of school, this one located in the town of Huesca. He set him up in a quiet boardinghouse in the Arco del Obispo (Bishop's Arch) near the old cathedral. Santiago was enchanted with Huesca. It was beautiful and it was steeped in history and legend. He spent his first pocket money for drawing materials to make sketches of it.

A friend from Ayerbe was commissioned by his father to see him through Virgil's *Aeneid*, Don Justo being determined that, by some means or other, his son should get some "culture." He had learned with bitterness that in the Spain of his day the physician was esteemed far more for his social graces and his background in the humanities than for his skill in surgery or his knowledge of medicine. And, like most self-made men, Don Justo

[26]

wanted his son to have the advantages he himself had never known

The Latin teacher in the new school was the antithesis of Father Jacinto—a befuddled but kindly old man whom his pupils loved and tormented. The geography teacher was young and energetic, demanding strict attention yet able to keep his students fascinated by what he taught. For the first time, Santiago's skill in drawing won recognition, the fine maps he made were the envy of all his classmates.

Here at Huesca Santiago was destined to repeat the experience he had undergone when his family moved to Ayerbe. Again he was the despised "new boy" among a throng of bullying school-fellows. From the moment he put in an appearance in the courtyard of the Institute, he was embroiled in quarrels and fist fights, from which he usually emerged in pitiable condition. Chief among his tormentors was one Azcón, a braggart from Alcalá de Gállego, an eighteen-year-old yokel fresh from the plow. Azcón decided Santiago was a natural for his sallies and he straightway dubbed him "Dago" and "Goat-flesh" (the latter because he was from Ayerbe and that was the current term of derision for people from there).

The "Dago" requires a bit of explaining. Santiago's mother had long since learned, as Don Justo's wife, to be frugal to the limit. Since her son was to go off to school for the winter term, she had made him a warm overcoat, cut down from an old one of his father's. But at this stage Santiago was shooting up like a beanstalk, so she made it with an eye to the future, and its long skirts flapped in the brisk wind as he walked, making him look like an Italian organ grinder whose monkey had played truant for the day.

"Look at the Dago!" Azcón would shout after him. "Where's the organ and the monkey?"

The same thing happened every day. Santiago would spring at Azcón and get the drubbing of his life. When the fight was over,

Explorer of the Human Brain

he would pick himself up as best he could, collect his books, which had been scattered in all directions, and limp meekly home. The nickname stuck to him. He was greeted with it whenever he put his nose out of doors. And this went on for two or three months, all because of a few extra inches of coattail!

Santiago then took the whole matter under advisement. "If I can beat Azcón," he thought, "the others will become my allies." So he started, secretly, upon a course to develop his physical strength and fighting skill so that eventually it might be possible for him, younger and weaker though he was, to knock out the school champion. He spent hours in the woods near by, climbing trees, hurling heavy stones, jumping over ditches. Months of this worked the longed-for miracle. He had already learned half-consciously the maxim that was to guide his lifework. "If you wish to succeed in difficult undertakings, put your whole will into your purpose, preparing yourself with more time and effort than are actually called for."

By the time he returned for his second year at Huesca, he had become so adept with the slingshot and the cudgel that Azcón capitulated and made his peace upon Santiago's announcement that, if he did not, he would drive a stone into his thick skull. He was "Dago" no more.

In all his gymnastic exploits of this period, which he calls his "muscular epoch," Santiago did not forget his love of art. As a result of his solitary exercises directed toward the laying low of Azcón, he came to see more clearly than before the beauty of the vegetable and animal worlds and preferred to depict it, rather than the beauty of the human world which had so intrigued him earlier. He now painted rocks, trees, wild flowers, butterflies, brooks churning their way through stones, rushes, and water lilies. He was not pleased with his sketches. He would try to approximate Nature's variety of hue and nuance with a kind of desperate eagerness—but it always eluded him. His efforts to reproduce colors exactly as they were in Nature led him to sharpen

[28]

his observation, and to paint and draw only from life, distrusting memory, which so often tends to oversimplification of line and tone

He even made a kind of color dictionary, starting with the pure colors, then grading off systematically into the various tints representing different degrees of saturation, each accompanied by a number and a picture of the object best exemplifying it. This worked well for rocks and insects, and even for wild flowers, but cultivated flowers—that was something else. How could he get “models” to study from? Cultivated flowers had jealous owners who had little sympathy for “poachers.” The resolution of this dilemma led to some sorry consequences.

For instance, there was the expedition in search of roses. Santiago had come to the “rose chapter” of his color dictionary and had to have a specimen of a variety known in Huesca as the “rose of Alexandria.” Fine ones grew in the garden of the railroad station. So one day when the guard was off somewhere, Santiago jumped over the fence and plucked some. But when he was already back outside the fence, the guard saw him and started to chase him, musket in hand. Santiago ran faster and was almost safe when, leaping over a brook, he slipped and sank up to his middle in the slime of the opposite bank. He couldn’t get out. Squirm as he might, he only sank in deeper. Finally, some washerwomen working in the stream near by saw him and pulled him out, with loud guffaws. He wanted to go off to undress and clean up his clothes, but the washerwomen took over, while he crouched in his shirt under a willow tree. In the meantime the guard caught up with him, but unable to lay hold of him without soiling his clean uniform, he decided to treat the whole thing as a joke—Santiago’s armor of foul-smelling slime had made him inviolable.

Such an adventure for the prize of a few flowers seemed lunacy to his more practical-minded schoolmates and Santiago became known all over Huesca as the “crazy Navarran.”

VACATION DAYS AGAIN

AT LAST the summer of 1864 came and with it vacation and the return to Ayerbe. But Santiago's carefree days were numbered. Don Justo announced to him that his cavortings with his old playmates must stop. Likewise his arty foolishness. The summer was to be given over to study in order to make next year's schoolwork a bit easier. This was a dash of cold water on Santiago's bubbling joy in freedom, but he settled down to it for a while. Then, unable to bear it, he resorted to artifice. He needed solitude for his work, he said, and the old pigeon house would be a fine place to study in. All right, said Don Justo, use the old pigeon house. This was a room adjoining the barn, which had a window opening upon the roof of the next house. From the window Santiago could keep watch on those of his household who were keeping an eye on him. He made a niche out of sticks and brushwood behind the chimney of his neighbor's house, making sure it could not be seen from his own. He put a seat in his eyrie and hid his art materials under it. A few novels were hidden there too. Whenever he heard footsteps, he would return to the pigeon house and bury his nose in the Latin text of Cornelius Nepos or delve into his algebra. When all was clear, he would go back to his brushwood cage again, to read or sketch or paint. His art subjects that summer were chiefly lugubrious, for this was his period of adolescent melancholy. In this mood he painted cemeteries, bleak winter scenes, the agony of shipwrecked sailors.

Santiago at this stage was beginning to develop a taste for literature. The library of the Cajal household contained a few novels, but these were withheld from the children, being regarded by Don Justo as guides straight to the everlasting bonfire. Unknown to her husband, however, Doña Antonia did allow her children to read some novels she had, dating back to the days before she was mar-

ned, books that she had kept hidden at the bottom of an old trunk. There were a few novels of Balzac, among other things, and the young Cajals devoured them furtively.

Santiago loved the poems of Espronceda,³ and he had bought a collection of ballads and stories of knight errantry, sold by the blind and by dealers in religious prints. These were all he had until one day he happened to glimpse from his hideout, through the garret window of his neighbor's house, a whole library of books mixed up with old pieces of furniture and frames covered with dried fruits. The neighbor, a confectioner, Señor Cuideras, was a man of taste in other things besides sweets, it appeared.

How could he get at this hoard without arousing the owner's suspicions and leaving telltale signs? He decided that for one thing it would be prudent, when filching the books (as he was already planning to do), not to touch any of the candied pears and plums that so enhanced the attractiveness of this extraordinary garret. Not right away anyhow. He would creep in in the early morning when the family was asleep, take the books out one at a time, putting each back in its place on the shelf before taking another. The plan worked perfectly. All summer Santiago lived in an enchanted world with Dumas père, Eugène Sue, Chateaubriand, Lamartine, Victor Hugo, Le Sage, Mariana,⁴ Quevedo,⁵

³ José de Espronceda (1819-42) Most distinguished Spanish lyric poet of his century, a kind of Spanish Byron, chief of the Spanish romantic school. Journalist and revolutionist who shared in the Liberal triumph of 1840.

⁴ Juan de Mariana (1537-1624) Greatest of all Spanish historians, a contemporary of Cervantes. The main work of his life was his *Historia de España*, written to let Europe know what Spain had accomplished. This work has been called the most remarkable union of picturesque chronicling and sober history that the world has ever seen.

⁵ Francisco Gómez de Quevedo y Villegas (1580-1645) Prose writer and poet. Clever satirist and epigrammatist, dramatist and picaresque novelist. He was the most gifted Spaniard of his time and a strong and honest man in a corrupt age. In witty observation and ridicule of whole sections of society he almost vies with Cervantes though his work is marred by affectation and cynicism.

Explorer of the Human Brain

and, most important of all, Defoe's *Robinson Crusoe* and Cervantes' *Don Quixote*

Santiago thus entered the world of literature chiefly by way of the French and Spanish romanticists, who were much in vogue at the time of his maraudings in the confectioner's attic. He was enthralled in those days by the elder Dumas and Victor Hugo, whose stories he later blushed to admit he rated higher than Goethe's *Faust*, and by Le Sage, whom he placed (to his later discomfort) above Cervantes.

He was disillusioned by *Don Quixote*. Wholehearted romantic that he was at this age, Cervantes' ironic realism gave him something of a jolt. He could not bear to see the hero of La Mancha vanquished. No doubt, he argued, the vulgar champions of common sense do win out in everyday life, but to have them win out in a work of art is intolerable. The protagonist of valor and virtue should triumph over the crass and the mean. For he took *Don Quixote* literally, not knowing that Cervantes' aim was to satirize the extravagances of the popular novels of chivalry and to found a novel on the firm ground of reality, on the truth of life itself. Only later, when the ebullience of his adolescence had passed, did he come to see the Spanish masterpiece in proper perspective.

It was in his maturer years, too, that he learned to prize *Robinson Crusoe* at its just worth. It is significant of the character of this man—who, like Crusoe, was to follow untraveled paths—that his reaction to Defoe's great book should be this: "What a supreme triumph it must be to explore virgin territory, to gaze upon scenes untouched by the hand of man, adorned with their original flora and fauna, which seem created expressly for this discoverer, as a reward for his outstanding heroism."

THE SECOND YEAR AT HUESCA

IN 1866, the third year of Santiago's schooling in preparation for the bachelor's degree, his brother Pedro went with him to the In-

stitute of Huester to enter upon his work there. Pedro now offered a striking contrast to his brother—he was industrious, studious, scrupulous, submissive, rarely straying from the path of duty. Fearing that Santiago's wildness might be catching, Don Justo separated the two boys, establishing them in different boardinghouses—Pedro in a quiet, suitable one, Santiago in the home of a barber, Señor Acisclo, to whom his father had apprenticed him. The latter move was not only disciplinary in purpose—to curtail the boy's free hours so that he would have less time for mischief, it would also give him an opportunity to learn a useful trade. For Don Justo had by now given up his ambitions for his elder son and was ready to resign himself to training Santiago for any occupation his inability left open to him.

This apprenticeship, much as Santiago hated it, was not an unmixed evil. He came to know the common people and he grew more humble, more modest, and more understanding. But at the moment his pride rose up against it. This punishment for his peccadillos was too shameful, especially for one steeped in the grandiose visions of the romanticists, as he had become of late. But there was nothing to do but yield to the humiliation of wielding a soapy shaving brush while longing for the more elegant paintbrush of a disciple of Velázquez.

The master barber, bad tempered though he was at times, was at bottom a kindly man, and he held out the consolation that if the boy would swallow his pride and put his mind on lathering beards, he might become in time a full fledged barber with a salary of three dollars a month, with tips besides. The barber's assistant, a rosy-cheeked Don Juan, wooer of housemaids and seamstresses, took Santiago over as his confidant, persuading him to write for him fulsome love notes and poems to the current sweetheart. As compensation for this, he was easy on him when the master was away, and even tried—with dismal failure—to teach him to play the guitar.

The days in the barbershop introduced Santiago for the first time to republican political views. Master barber and customers regaled

Explorer of the Human Brain

one another with the latest news of the sporadic revolts against the regime of Isabel II. Some of the once-lauded generals—for example, Prim, who had won glory for himself in the Moroccan war, and Moriones and Pierrad—were now inciting timid insurrections. Without fully understanding the issues involved, Santiago, the individualist, hater of all authority, was from the first instinctively on the side of democracy and of the people, he would have liked nothing better than to defend a barricade in a revolutionary encounter. He won over his master completely by drawing pictures of the busts of the two generals (he was intrigued besides by Pierrad's classic profile) and penning some doggerel verses to Liberty. His leisure increased as his master's favor grew.

One day he and Pedro found a five-dollar gold piece in a rubbish pile near the Hermitage of the Martyrs. With it they bought a pistol they had long been gaping at in the window of a gunsmith's shop. The purpose of this was twofold: to get a thrill out of posing as revolutionists and also to hunt partridges and rabbits in the Cajal family tradition. But, unlike their father, they were poor hunters from first to last. Bad hunters though they were, Pedro and Santiago were enormously adept in the use of the slingshot, which proved especially useful in the battles of the schoolboy gangs. In fact, Santiago's reputation as a stone slinger became so widespread that children hid from him on their way home from school. One such child was a slender little girl with honey-colored braids, blue eyes, and coral lips—a typical Marguerite. Her uncle had warned her against that incorrigible rascal, the doctor's son from Ayerbe. So she fled in terror to her house on the Calle del Hospital whenever she saw him approaching. No one would then have believed that this timid little girl would one day become his wife.

APPRENTICED TO A COBBLER

THE SCHOOL YEAR of 1866 came to an end at last. Because of his constant skirmishes with his professor of Greek, Santiago was sure

he would fail in his examination and so he did not even present himself at it. His father trembled with exasperation when he heard of this and resolved to beat this recalcitrant son into shape if it was the last thing he did. He brooded upon what occupation would prove most hateful to him and determined to give him a big dose of it. He finally settled on cobbling. By the end of June he had apprenticed Santiago to a shoemaker, an uncouth man who put him through several varieties of torture. Santiago had to sleep in a garret full of mice, he had wretched food to eat, and was strictly deprived of pen, pencil, or paper. Never before had his life been so drab and never was his imagination more alive than on those nights when he peopled his dirty attic with gorgeous fantasies. His mother was fearful for his health and sometimes found a way to slip him pastry and tempting bits of meat. He finally got a pencil, bought with a tip given him by a countess of fourteen who came to the shop one day to have a shoe repaired.

Later he became the apprentice of another shoemaker, Señor Pedrín, a more cheerful man than his old master but equally harsh with his assistants. Santiago's skill as a cobbler soon became so widely known that another shoemaker, Fenollo, the best in town, engaged him. Since he was now making boots for the richest people of the community, especially the young ladies—boots with ornamented toecaps, open work, and dainty curved heels—Santiago had at last found something on which to unleash his stifled artistic urges.

He was still working for Fenollo in 1867 when another of the insurrections against Isabel II broke out. The cause of liberalism was gaining strength among the masses, its growth spurred by their hatred of the Conservatives for the recent shooting of Liberal leaders. A skirmish took place at Limás de Marcuello, a village not far from Ayerbe. Before this encounter, the people of Ayerbe had been rejoicing in the triumphs of the rebel generals, who were once again inciting revolution against the queen and her current favorites. A few hours before the battle, an infantry division of

Explorer of the Human Brain

loyalist troops, led by General Manso de Zúniga, paraded in the Plaza Baja de Ayerbe, resplendent with burnished cuirasses, their swords flashing in the morning sun. The squadron marched directly to Limás and soon there was a distant sound of shooting. The town of Ayerbe was in a ferment of anxiety.

Some of the boys of the town, including Santiago, hurried to a hill overlooking Limás to see the fighting. It had ended by the time they got there. The queen's soldiers, who, only a short time before, had been so impressive in their blazing armor, were now marching silently. General Manso de Zúniga rode in the midst of his disordered ranks, he was dying, or already dead, as he sat upright on his horse, his body supported by one of his officers. The column was closed by the wounded men, groaning as the pack horses carrying them stumbled over the rough road. This was a picture of war that Santiago was never to forget. The battle had been a victory for the rebels. They had routed the queen's troops in this encounter, as they were often to do until the end of her reign. Don Justo was kept busy tending both the wounded loyalist soldiers brought back openly to Ayerbe and the insurgents hiding in the villages and mountains near by.

It was when looking at the corpses strewn about the battlefield of Limás that Santiago first felt the full reality of death. "How supremely tragic," he wrote long afterward, "is this abandonment of the spirit and this unresisting surrender of our organs to the disintegrating effects of cosmic forces. And with what distressing indifference Nature casts away, like vile dross, the masterpiece of her creation, the brain of man, in which the universe mirrors itself."

BACK AT SCHOOL AGAIN

SANTIAGO had been a shoemaker's apprentice for a year when his father decided he had been punished enough and might now

[36]

return to school Don Justo even capitulated to the extent of allowing him to enroll for a course in drawing Santiago enjoyed this to the full and was tireless in his art work His professor said he was the most brilliant pupil he had ever had and even took the trouble to go to see Don Justo to urge him to allow his son to devote his life to art. But Don Justo was not to be persuaded

Santiago was getting along well in rhetoric and poetics too He cared less for logic and psychology as they were then taught—with a strong flavor of medieval scholasticism Yet, at times, he was almost carried away by the eloquence of his professor of philosophy, Don Ventura, disciple of Aristotle and of Saint Thomas Aquinas, who daily denounced the teachings of the rationalists—Locke, Condillac, Rousseau, and Voltaire But in his more wary moments Santiago was on the side of rationalism, with an instinctive distaste for all dogmatism

Don Ventura was to be the cause of Santiago's next fall from grace One day while walking near the Plaza de San Domingo, the boy saw a freshly plastered wall This was irresistible Soon it was covered with caricatures of his professors—life size His masterpiece was Don Ventura, with his blind eye, his flat nose, and his clean-shaven priest's cheeks Some schoolmates happened along at just that moment They roared with laughter and began throwing stones at the pictures, with jibes and jeers for the teachers they portrayed

They were busily engaged in this when along came Don Ventura Santiago fled But Don Ventura probed until he found out who had made the drawings The next day he showered Santiago with a torrent of abuse, finally throwing him out of his classroom From then on, the boy led a dog's life in Don Ventura's course, though he did all he could to show his repentance for his thoughtless cruelty, which he too condemned But in the end Don Ventura refused to let him take the final examination in his course, turning him over to his colleagues for examining, after giving them a full account of what he thought of young Cajal His confidence

utterly shaken, Santiago did the best he could, but he failed completely

He could not face his father. So with a few companions in similar straits he tried to run away to Zaragoza. The boys got as far as Vicién when night fell and one of them suggested that they go to visit an uncle he had there. This uncle gave them a good supper and a place to sleep. The next day their plan for flight had melted away and they all went home, including Santiago, sick at the thought of Don Justo's anger and his bitter disappointment.

THE SEPTEMBER REVOLUTION

THE BLEAK SUMMER passed somehow for Santiago and at its end came the September revolution of 1868. Although reactionary politics had so long been in the saddle, the principle of constitutional government had been established in Spain and had not been entirely forgotten. Once championed by a mere handful of intellectuals, the cause of liberalism was now espoused by a large proportion of the civil population. Throughout the later years of Isabel's reign the Liberal insurrections had become constantly more frequent and more menacing. The attacks were directed chiefly against the queen herself, whose capriciousness and irresponsibility vitiated any hope of permanent peace or of national stability. Radical newspapers, which the Government was unable to suppress, exposed her immorality. Her former adherent, General Prim, converted wholly to the Liberal cause, had led an unsuccessful revolt against her in 1866, and, though he failed, her position had been weakened by it. The final blow to her supremacy came with the death of her two stalwarts—General O'Dónnell in 1867 and General Narváez in 1868. Her doom now came upon her swiftly with this new uprising, led by her former lover Serrano.

On September 17, 1868, the queen and her children had gone to the seaside town of San Sebastian. Already there had been deep

rumblings of mutinies and *pronunciamientos*. On the twenty-eighth, Isabel heard that her defenders had been defeated in a battle at Alcolea and that there was rioting in Madrid. On the following day she fled with her family from the country she had misruled for almost thirty years. Accepting the hospitality offered by her former lady-in-waiting, now Empress Eugenie of France, Isabel and her children took refuge in the royal chateau at Pau.

Back in Spain the Liberals were exulting. The little town of Ayerbe had always been ardently Liberal, and its 600 inhabitants to a man rejoiced in the success of the revolt against the forces of conservatism and tyranny, loudly cheering the leaders, Serrano, Topete⁶ and Prim.

As the telegraph brought news of the victory of Alcolea, peasants swarmed into the town armed with old guns, swords, ponnards, and even sickles. A volunteer garrison of these rough patriots was established in the palace of the Marquis of Ayerbe, over which a red flag now floated. The portraits of Isabel were torn down from the public buildings and burned in the town squares. In the general revolutionary zeal, the beautiful bells of Ayerbe were sent off to the national mint to be melted down to make money. Soon as in a later day in the fictional town of Adamo, other bells had to be bought, for the people could not live without them.

Two years later, on June 25, 1870, Isabel would formally abdicate from the toppling throne she had deserted. She was then forty and her son, Alfonso, Prince of Asturias, was just thirteen.

⁶ In September, 1868, the squadron at Cadiz under the command of Admiral Topete had mutinied and its action had been a signal for a general revolution.

3. *The Marvelous Workmanship of Life*

*Is it the mind that controls the bewildered body and points out the way to physical habits uncertain of their affinities? Or is it not much rather an automatic inward machinery that executes the marvelous work, while the mind catches here and there some glimpse of the operation, now with delight and adhesion, now with impotent rebellion? **

—GEORGE SANTAYANA

IN the fall of 1868, Santiago, back at school again, suddenly began to take education seriously. Perhaps it was because he was now studying subjects for which he had a natural inclination and an instinctive respect—chemistry, physics, and natural history. Chemical experiments seemed to him a sort of magic, and physics the science of miracles. He was overwhelmed with regret that he had not mastered mathematics as he should have done in earlier years, and he began to review it now. He found (as he was to say later) that “the whole universe, both in the realm of the infinitely great and in that of the infinitely small, is constructed in accordance with the formulas of a sage geometry and an admirable system of dynamics.”

Delighted by his son's reformation, Don Justo began to take hope that he would be able to make a modern Galen out of him.

* The quotation above, from *Reason in Common Sense* (page 212), is used with the kind permission of Charles Scribner's Sons, New York, and Constable and Company, Ltd, London.

after all. Before any relapses on Santiago's part could dash these dreams to bits, he enrolled him in the premedical curriculum at Zaragoza. As a further safeguard, Don Justo installed him as a kind of attendant to a well known surgeon, Don Mariano Bailo, a friend and former classmate of his. Santiago keenly relished all this. But disappointment lay in wait on his arrival at Zaragoza. Two years behind his companions of Huesca days, all of whom had formed new friendships at the university, he found they had no interest in him and he was left friendless and alone. This was too severe a punishment for his scholastic backwardness. He looked for solace now, as he was to do in all the evil moments of later years, in the beauty and the infinite variety of Nature. Now it was the green-shaded walks along the Ebro that gave him a measure of comfort. The Ebro was the first large river he had ever seen. His curiosity about it fully stirred, he tried to find its source, trudging upstream and down again in his scant hours of leisure.

Two of his professors at Zaragoza were to stand out in his later recollections. The first was Don Florencio Ballarín, teacher of natural history, a man already in his seventies. Because he was an active Liberal, he had been persecuted by Ferdinand VII (Isabel's father) and henceforth had nothing but contempt for the whole breed of Bourbons. Don Florencio was the first teacher in Santiago's experience who expressed the conviction—and carried it out in practice—that scientific teaching should be objective, bulwarked at every turn by careful experiment. To this end, he conducted his own classes chiefly in the botanical garden and the museum of Zaragoza rather than in a formal lecture hall. He was a man of violent temper, often irritated beyond endurance by the restlessness of his young neophytes. To keep them interested in the work at hand, he instituted a novel teaching device. He would assign the defense of a moot issue to one student, to whom the others would propound all the objections they could think of. One day a brilliant boy, Semre (later to become an army surgeon and one of Cajal's friends), gave a defense of the view, popular at the time,

Explorer of the Human Brain

that the blood in the veins of man was toxic to his organism because of the carbon dioxide it had accumulated, which had to be driven out of the body by way of the lungs

Santiago, brought up on the same textbook as Semac, Béclard's¹ *Physiology*, asked nervously whether it was not the lack of oxygen in the veins rather than the presence of carbon dioxide (a harmless gas) that was noxious to the body—the oxygen having been burned up in the capillaries in the course of the respiration of the tissues. This was an original idea for a student of the time, but he expressed it so clumsily that Don Florencio silenced him at once, calling him, in effect, a rustic clown still wet behind the ears.

But in spite of his moments of injustice, the boys revered Don Florencio as a true scientist. Another thing added to his popularity. Understandably absent-minded in his seventh decade, he would sometimes come to class, utter a blurred "Se-ñores"—and at once it would be evident to him and to the boys alike that he had forgotten his teeth! Whereupon a holiday was declared, to everyone's satisfaction. Whether this forgetfulness was always accidental, no one dared say.

Completely different was Santiago's professor of chemistry, Don Bruno Solano. Cajal describes him in his *Recuerdos de mi vida*:

Eloquent, fiery, affable, not incapable of severity when occasion demanded it, he made his class a temple where we heard, enraptured, the story of the loves and antipathies of the different substances—the adventures of oxygen, a kind of Don Juan, a passionate and irresistible conqueror of the virginity of elements, the revenge of hydrogen, a jealous lover responsible for much widowhood among the molecules, and the intrigues of heat and electricity, ancient duennas capable of upsetting and divorcing even the closest and most stable molecular matrimonial bonds. Apart from these poetic extravagances, which he did not overdo, Solano was a fine teacher.

What pleasant, even angelic speech he had! What supreme skill in making understandable and fascinating, by brilliant comparisons, the

¹ Pierre Augustin Béclard (1785-1825) French anatomist

most abstract points or the most complex ideas! In this he resembled the great English physicist Tyndall, the great Echegaray,² and that master popularizer of science, Duhem.

I confess that when I visit Zaragoza one of the things which sadden me most is the absence of my prematurely lost colleague. [Solano died young after a surgical operation.] He dined each in the Café Suizo, where his friends and admirers met together, were a spiritual feast. His popularity was great—he deserved to have it. What has since come to be called “university extension” was one of the many things he initiated. He did not keep his science only for the privileged few who were enrolled in his course, but spread it widely among the lay public, creating bonds of interest and mutual appreciation between the professor’s chair and the school, the laboratory, and the factory. For he thought that science should be haled up with life to inspire it and to guide it. The exquisite combination of the artist and the thinker, both of which have enthralled him to see the grandeur of the commonest things.

Solano possessed in addition a magnificent literary gift. He was a born writer, although he had never ventured to write. Yet his brilliant expressive power revealed by the rare scientific and popular articles he published here for the daily paper, and his extraordinary insatiable discourse on the direction of modern chemistry.

This description of an outstanding Spanish scholar is of interest not only because it is Cajal’s tribute to one of the teachers who influenced him most, but also because much of the characterization in it was to apply equally well to Cajal himself as his genius unfolded throughout his youth and maturity.

NOVITIATE IN DISSECTION

WHEN SANTIAGO was seventeen years old and soon to be fully registered in the medical course, his father secured an appointment to serve in Zaragoza as a physician paid by the Government to

² José Echegaray y Eizaguirre (1832-1916), Spanish dramatist, winner of the Nobel Prize for Literature in 1904.

Explorer of the Human Brain

work in the clinics for the poor. He also became professor of dissection in the Faculty of Medicine. So the family shortly afterward moved to the university town. This appointment was a boon which Don Justo accepted with satisfaction, feeling it to be the reward due him after his years of toil as a country doctor. At once he was filled with zeal to make a skillful dissector of his son. And this time Santiago had abilities and interests that matched his father's wishes. Besides, even if he hadn't had, who was there who could shirk under such a taskmaster? Don Justo, finally, proved to be a natural-born anatomist. He and Santiago spent hours in the dissecting room hidden away in the garden of the old Hospital of Santa Engracia, taking apart muscles, glands, nerves, and blood vessels, to check what the anatomy books had to say about them. As Santiago would write later "Before the imposing anatomical slab covering the dissecting table both brain and stomach protested at first. But soon they became accustomed to it. Henceforth I saw in the dead body, not death with its host of melancholy thoughts, but the marvelous workmanship of life." His interest in anatomy and the development of his remarkable skill in dissection dated from this period of his youth.

Father and son were alike in this: as the difficulties increased, so too did their determination to get to the root of the teasing problems that had perplexed the masters in the field. They worked with the textbooks of such great ones as Cruveilhier³ and Sappey⁴ spread out on the tables beside them. They worked tirelessly—Don Justo was indefatigable himself and did not tolerate fatigue in others—during what hours the father could spare from his patients and his teaching and the son from his other studies. They were now united on another point, too. Santiago's pencil, which had been the source of so much grief between them, now became a valued item of their equipment. It sketched with exactness and

³ Jean Cruveilhier (1791-1874) French pathologist. He held the first chair of pathology in the Faculty of Medicine of the University of Paris.

⁴ Marie Philibert Constant Sappey (1810-96) French anatomist.

artistry the intricate structures their researches revealed. His portfolio grew fat as he added drawing after drawing. He made a huge collection of anatomical water colors, of which Don Justo was inordinately proud, they even planned to publish an atlas of anatomy, using these water colors, but to get out a worth while one, excellence in the technique of color reproduction was essential, and the processes in use in Spain at the time were not good enough to make this project feasible.

STUDENT AND TEACHER

As a result of his hard work and his evident talent in dissection, during his second year Santiago was granted an appointment as assistant in anatomy. He multiplied the small earnings this position brought by tutoring students in anatomy. In spite of all this outside work and a few minor excursions which he permitted himself at rare moments into art for art's sake, he passed his course creditably this second year—partly, he says (no doubt, with undue modesty), because a certain professor, fired with zeal for democratic principles, had altered the traditional scheme of marking by grades into a mere "pass" or "fail." Although he claims to have profited by this more lax method, Santiago was no believer in it. It is interesting in view of modern trends in this direction in our American schools, and of the fact that Cajal later himself became a professor, to see what he says about it.

I confess that I have never been able to see the educational advantage of the suppression of marks. At an age when laziness and heedlessness find so many opportunities to assail the will, what harm is there in stimulating emulation and even vanity? Let the miracle be done even if the devil does it! If there remains in the heart of the student any residue of unwholesome competitiveness, life will soon look after doing away with it. The important thing is to add to the scientific heritage acquired and to keep up the habit of work.

Explorer of the Human Brain

Encouraged by his professor in anatomy, Don Manuel Daina, who had a weakness for him because of his skill in dissection, Santiago undertook a competitive examination for a prize in anatomy. On the day the examination came, he went up alone. He was told to write about the inguinal ring, the region surrounding the groin, the lowest part of the abdominal wall near its junction with the thigh. He proceeded to do so at length and in detail, clarifying his description by drawings and diagrams that would have done credit to a master. Confident of his success, he waited and waited, overhearing rumbles of angry talk from an adjoining room in which the judges were assembled going over his paper. What could be going on in there? Finally the judges came out, Daina beaming his congratulations. Santiago had won the prize well enough. But Don Nicolás Montello, professor of surgical pathology, as he flung out of the room, cast a scornful look at Santiago, saying, "You are not pulling the wool over *my* eyes. Your paper was copied!" Santiago flew into a rage and would have given the professor a piece of his mind had not Daina flown to his defense. The incident had a happy ending, but Santiago, remembering it, was never to show himself at an examination for a prize again.

During this period the medical schools of all the world, but especially of Spain, were going through what Cajal was later to call the Pre-Bacterial Era. Many of the professors, of a type too rare today, combined with their knowledge of medicine classical scholarship and a love of the arts, and quite naturally they tended by temperament to react violently against the materialistic trends (already beginning) which were soon to dominate chemistry, histology, and later the new science of bacteriology.

At about this time there appeared a revolutionary book, Virchow's ⁵ *Cellular Pathology*. Following in the steps of the German

⁵ Rudolf Virchow (1821-1902). Great German scientist and liberal. He envisioned the body as a kind of "cell state" with its specialized cells comparable to the human specialists—doctors, lawyers, bakers, carpenters—who must exchange their products or services with one another for their

anatomist Theodor Schwann,⁶ who had propounded the theory that the cell is the basic structural unit of all living organisms, then a totally new idea, Virchow applied this concept to the study of the cell in conditions of disease. This book provoked a controversy between Santiago and his professor of pathology, Don Genaro Casas, a friend and fellow-student of his father's and a teacher of great ability. Santiago was intrigued by Virchow's thesis that the cell is an independent living entity and the chief malefactor in bodily ills. The opposing school of thought—the vitalists and the animists, of whom Don Genaro was one—held, on the contrary, that the cell is not the basic structural unit of the organism but a kind of outpost defense protecting the body against attacks from the world without. One day in class, when questioned about inflammations, Santiago had an opportunity to display his new knowledge, so much at variance with his professor's views. He declared, with a boldness he was later ashamed to recall, that inflammatory exudations (pus formations) were not a defensive reaction on the part of the life principle inherent in the body but merely the result of local irritation, which stimulated the multiplication of cells at the injured spot. "As I understand it," he said, "the central forces within the body, if such forces really do exist [and he indicated strongly that he doubted it], take no part in the process, as is proved by the statement of Virchow that inflammations may occur in tissues which do not contain any nerves or blood vessels."

Don Genaro was not annoyed, as he might have been, by such

own survival and for the well-being and enrichment of the community as a whole. Similarly, he conceived of society as "the social organization of cells." Each of these two aspects of life was profoundly interesting to him, before he was twenty-five years old he was both active politically and was the editor of a medical magazine.

⁶ Theodor Schwann (1810-82) German anatomist and physiologist, professor of anatomy at the University of Louvain and noted as the founder of the cell theory. "Cells" are the little compartments or chambers observed in all tissue when it is examined microscopically.

Explorer of the Human Brain

arrogant heresy from one of his pupils. He gently tried to argue the point and to explain that even in tissues without nerves or blood vessels, when pus gathers about the site of any injury, this represents a defensive reaction of the vital principle of the body against harmful stimuli from outside it. He pointed out the essential purposefulness of such a defensive reaction, by which the organism tries to remove the cause of the trouble and repair the damage that has been done. Such a purposeful action indicated the existence of an immaterial principle within the body which regulated and co-ordinated its activities. This could be nothing else, Don Genaro urged, than the vital force, another name for the "vegetative soul" of the medieval scholastic philosophers.

All this seemed misplaced poetic fancy to the rationalistic Santiago. To him—and he said so—the vital force or vegetative soul is a myth invented to cover up our real ignorance of how these commonly observed processes come to pass. His stubbornness caused quite a scene in the classroom. The next day when Don Genaro met Don Justo at the university, he said, "You have a son who is as stubborn as a burro. Once he is sure he is right about a thing he won't give up his idea, even if the lives of his parents depended on it." Santiago at once regretted his forwardness and apologized for it to Don Genaro.

Professor Ferrer, instructor in obstetrics, reproached him one day for his irregular attendance at his classes.

"My work in the dissecting room takes up all my time," Cajal answered, "but I have done the assignments and have kept up with your subject fairly well."

"That we shall see," replied Professor Ferrer. "Tell me about the origin of the membranes of the fetus."

This was one of his pet themes and he had developed it in his lectures in detail. So, accepting the challenge, Santiago went to the blackboard and drew colored diagrams showing all the stages and transformations involved in the development of the unborn

child. Professor Ferrer, be it said to his credit, instead of nursing his annoyance, followed the demonstration with delight.

"The lecture you have just given us assures your passing this course with an 'excellent' even if you never come to class again," he said when it was done.

Cajal profited by this blanket permission to stay away as much as he dared, condescending to come to class on rare occasions when his other work permitted it. His success in the demonstration, he tells us, was sheer luck. His interest in anatomy had led him to an intensive study of the embryo. If the professor had asked almost anything else, his total ignorance of the course would have been laid open to them all. The rest of his classmates who knew him well guessed this to be the case but were too loyal to give him away. And besides, the course in obstetrics, like many others at the university, suffered from a lack of laboratory facilities and lack of opportunity for direct experience—thus tending to become pure theory. As Cajal was to point out later, "to study positions and presentations in childbirth without having been present at a single delivery is like learning how to shoot without ever having held a gun."

"SICKNESSES OF YOUTH"

Cajal had given his work in the dissecting room as an excuse for cutting Professor Ferrer's obstetrics course as often as he could. But it was not an altogether truthful excuse. For although he worked hard, he had some hours of leisure, which he chose to spend with one or the other of his three manias of this period—literature, gymnastics, and philosophy. He calls these "the sicknesses of youth."

During this epoch of social and political upheaval, Spain was deep in the throes of literary romanticism. The newspapers blossomed every day with hymns and odes to passing events, which in the eyes of these exuberant contemporaries took on a kind of epic

grandeur Victor Hugo, Espronceda, Zorrilla,⁷ and the oratory of the revolutionary leader Castelar were the literary lodestones of the age, attracting a swarm of imitators "As was to be feared," Cajal says, "sentimental temperaments like mine suffered more acutely from this fashionable disease than did the cooler, more practical fellows I took to making verses, composing legends, and even writing novels. After some years of this, convalescence finally set in, and with it came the bitterness of disillusionment." Of all his fellow-victims only one, Joaquín Jimeno, continued to write. He became a man of literary taste and talent, editor of a newspaper and an outstanding politician. Thanks to his good friend Jimeno (so he says), the local newspapers published some of Cajal's verses. He had very little use in his later years for these poetic excursions but they were probably not nearly so black as he painted them in his *Recuerdos*.

One of the idols of the time was Jules Verne, who fired Cajal's imagination as did no other literary figure he encountered in these years. In imitation of the *Voyage to the Moon*, *Five Weeks in a Balloon*, and *Round the World in Eighty Days*, Cajal wrote an enormous biographical novel about a trip to the planet Jupiter. Here the human traveler encountered fantastic animals in the form of men, but infinitely larger, and since in comparison with their huge bulk he himself was the size of a microbe, he remained invisible to them. Cajal's later description of this youthful work, which testified so strikingly to the creativeness that was in him, is so interesting that a bit will be quoted here.

Armed with all sorts of scientific apparatus, the intrepid hero commenced his exploration by stealing into a cutaneous gland. He afterward entered the blood, sailing on a red blood corpuscle, watched the epic struggles between leucocytes and parasites, observed the remark-

⁷ José Zorrilla (1817-93). Direct successor to Espronceda (see note on page 31). A writer of great national spirit, dramatic insight, and lyrical spontaneity, a kind of Spanish Sir Walter Scott. Popular novelist, dramatist, and poet.

able visual, acoustic, muscular and other functions, and finally arrived at the brain and discovered—think of it!—there was nothing trivial about it—the secret of thought and of the voluntary impulse. Numerous colored pictures selected, of course, from the histological books of the period (Hunke, van Kempen, Kolbier, Frev, and others) illustrated the text and showed in lifelike fashion the exciting adventures of the hero, who threatened more than once by the viscous tentacles of a leucocyte or of a vibratile corpuscle, freed himself from the danger by ingenious efforts. I am sorry that I have lost this book, for it might perhaps have been transformed in the light of the modern revelations of histology and bacteriology, into a delightful work of scientific popularization.

At eighteen Cajal was sturdy and agile, with a smug conceit that he was the strongest member of his class. He was shortly to be undeceived—he never had much luck in cherishing illusions. A classmate, José Moriones, later to prove a lifelong comrade, got tired of hearing him boast of his fine muscles. He challenged him to a contest with the wrists, a form of battle then very popular among undergraduates. Cajal was “licked” to the last ditch. When he had caught his breath, he asked his victorious foe how he had developed such iron arms and hands.

“Through gymnastics and fencing.”

“If that is the case,” said Cajal, “I’ll beat you in six months.”

For reply, Moriones cast him a half pitying, half-contemptuous smile. But he did not know the champion slingshot-wielder of Averbé.

The next day, unknown to his father, Cajal went to the gymnasium of one Poblador, located in the Plaza del Pilar. He and the gymnast struck a bargain by which Cajal was to give Poblador lessons in muscular physiology, knowledge of which Poblador thought would give his professional instruction a more distinguished tone. In exchange he would give Cajal lessons in physical prowess.

With characteristic zeal, Cajal threw himself into this business,

Explorer of the Human Brain

devoting two hours a day to the gymnasium. Each day he systematically added more weight to the balls he threw about, and each day he did more turns on the parallel bars. By dint of all this, he did eventually beat Morones red in the face and became the superman of his class. Poblador had never had such an advertisement of the efficacy of his teaching.

This is Cajal's description of himself during this "epoch of the biceps"

In physical appearance I was not much of an Adonis. Broad in the shoulders, with enormous muscles, I had a chest circumference of 112 centimeters [about 45 inches]. When I walked it was with that inelegant and rhythmic strut characteristic of the side-show Hercules. Like the paws of a beast, my hand unconsciously crushed the hands of my friends. A walking stick, which was transformed into a straw by my blunted sensibilities, had to be replaced by a terrifying iron bar (weighing 16 pounds), which I painted to imitate an umbrella case. I was proud and even insolent with my coarse porter's figure, and burned with eagerness to test out my fists on someone.

A certain incident occurring at this time shows both the results of his athleticism and the general atmosphere of that period of quixotic romanticism. During Cajal's university days a pretty, blue-eyed girl lived in the Calle del Cinco de Marzo. Her classic grace won her the name of Venus de Milo among the students. Smitten by her loveliness, many of the boys would stand for hours under her balcony watching her windows and hoping for a glimpse of her. Cajal was soon numbered among them. It was more than love, it was the rapture of the artist gazing on a thing of beauty. He never dared to write to her or to speak to her.

One evening as he was pacing the Calle del Cinco de Marzo in the hope of seeing her, a stout fellow of his own age came up to him and forbade him to walk on that street. Cajal did not know the boy but deduced from the confidence of his manner that he was a certain student in the engineering course who by thrashing all his rivals for Venus' glances had gained command of the ter-

things he could do for one's muscles. He later became a distinguished officer in the Spanish Engineering Corps.

Apart from the affair of the Venus, which had hardly any basis in reality at all, Santiago at this age had little interest in girls. Perhaps this was due to his concentration on physical development, which, according to many psychiatrists and educators, often retards the development of the sexual instincts in young men and women. To him the prettiest girls were hardly more than winsome pictures to look at. They did not stir him at all. And the girls did not find Cajal very alluring either. They preferred graceful elegance to his robust sturdiness, and suave distinction to his untutored directness.

The era of the gymnast was promptly succeeded by the era of the philosopher. As he put it, the poor association cells of his brain, forgotten in his eagerness to cultivate his muscles, cried out loudly for their right to live. He began to come to the conclusion that it was more worthy to defeat his adversaries with reason than with blows. He absorbed himself in thoughts about God, the soul, the origin and destiny of the universe, and the meaning of life itself. His interest was not altogether sincere. He was less concerned with arriving at the truth of things than with dazzling his friends by his cleverness in dialectics and his skill in contriving and detecting sophistries. The future rationalist became at this stage an absolute idealist, disciple of Berkeley and of Fichte. He set himself the thankless task of trying to prove to his comrades that the world about them, which seems so solid, actually has no real existence, except in one's own mind. At bottom, he was as firmly convinced of the reality of the external world as they were, he just liked to play with ideas. Soon he came to feel that such mental gymnastics as he had now substituted for the physical ones contributed little to his intellectual or spiritual development except so far as they gave his mind agility and ultimately led to what he regarded as a healthy skepticism. Later on he became genuinely interested in philosophy, feeling that it built up in him the proper

mental condition for his lifework of scientific investigation, in which the search for truth, at no matter what cost to the searcher, was to be the guiding star of all his strivings

AFTERMATH OF REVOLUTION

DURING THESE YEARS in which the ferments of later adolescence were bubbling up in Santiago, his country too was going through a period of inner turmoil. Although the corrupt regime of Isabel II had ended with the Revolution of 1868, all was far from well with Spain. Long years of troubled times lay ahead. Once the causes for which the leaders of the Revolution had joined their forces had been brought to a successful conclusion, disagreement and rivalry arose among them. As soon as the queen and her satellites were out of the way, the Provisional Government that had been set up to direct affairs issued manifestoes announcing the policies of the Liberal rulers. These made it clear that the new government was to be a constitutional monarchy, with sharp limitations on the powers of whoever was chosen king—and he would have to be chosen from some dynasty other than the Bourbon house of which Isabel had been the latest Spanish representative. A new Constitution was drawn up in record time—one month—by the Cortes appointed for the task. By it the legislative power was to be vested in two Chambers. Freedom of worship, trial by jury, and individual liberty were proclaimed. But the much-vaunted Constitution soon proved unsatisfactory to almost everyone. The Conservatives decried its anticlerical spirit. The Republicans declared it to be inadequate, saying that its reforms did not go far enough. The Republican leader, Castelar, the greatest orator in Spain, made fiery speeches condemning it.

But the Constitution had, after all, been voted in and the immediate problem was to find a king. All the possible Spanish candidates were found to be unsuitable for one reason or another,

and so the former Generals Serrano and Prim, now respectively Regent and Prime Minister of the Provisional Government, "shopped" around Europe for a monarch. One of the royal princes to whom the crown was offered was Leopold of Hohenzollern-Sigmaringen, though he eventually declined it, his candidacy led to the Franco-Prussian War and the fall of the Second French Empire.

Two years after Isabel's flight Spain was still in tumult. At length the crown was accepted by Amadeo, second son of Victor Emmanuel II of Italy. He had been chosen by a small majority of the Spanish Cortes, only 191 of a possible 311 votes being cast in his favor. Amadeo, a conscientious young man of twenty-six, arrived in Madrid in January, 1871, eager to fill his high post worthily. But his position was hopeless from the start. The first misfortune that befell his reign was the murder of Prime Minister Prim, bulwark of his regime, in the streets of the capital.

Isabel had formally abdicated in June of the year before, but a powerful group that had remained loyal to her had already hailed the young Prince of Asturias, her son, as Alfonso XII, their legitimate king. This group naturally opposed the rule of Amadeo, declaring him a usurper. Another group of the population was bitterly opposed to the House of Savoy (from which Amadeo was descended) because of its conflicts in the past with the Spanish King of Naples and the Duke of Parma and because of its curtailment of the Pope's powers. It was impossible to get any real support for Amadeo from the split ranks of the Government and the numerous powerful factions agitating outside it. The followers of Isabel's son were already in arms, and there were Republican riots in Madrid and other large cities. Realizing the insurmountable difficulties that confronted him and the constant danger to which he was exposed, Amadeo abdicated in February, 1873, to return to his native Italy.

Upon his departure, the two Chambers of the Cortes united to become a National Assembly and voted Spain a Republic. By this

time the country was in chaos. The North was almost wholly for Don Carlos, brother of Ferdinand VII, who had long ago put aside Cádiz's claims to the throne in favor of his daughter Isabel. Bona Jervis was practically independent of the Government, and Andalusia was ruled by Sardinia's interests. To make matters even more confused, the Republicans were divided among themselves as to whether Spain should be a federal republic like the United States, or a unitary state like the Republic of Switzerland, or a confederation of republics managed by the other leaders, Salmerón and Segura. A federal republic was eventually decided upon, but even then a serious dispute over what unit should constitute it—a better one—old provinces, or some other geographical entity.

Meanwhile conditions in the provinces were becoming worse and worse. Madrid, Cádiz, Seville, and Cadix had become virtually independent of the rest of the country. Catalonia and Valencia had already seceded. Riots were mutinying everywhere. Killing, theft, robbery, prostitution were rampant and private property confiscated. In Catalonia the army and navy joined the revolution, and it took the intervention of British men of war to prevent them from embarking on a course of piracy. There were repeated revolts in the provinces of the Republic. Pío Margall was replaced by Salmerón, who two months later (in September, 1872) was replaced in his turn by the more radical Castelar.

This was the state of affairs in Spain when Santiago Ramón y Cajal came of age, and the turbulence of the period was shortly to have an intimate bearing on the events of his life that were soon to follow.

4. Cuban Interlude

Let us love our country even if it is only for her misfortunes

—RAMÓN Y CAJAL

SANTIAGO had hardly reached his majority and obtained the degree of Licentiate (Graduate) in Medicine when he was drafted into the army. In the summer of 1873 the political situation in Spain was especially precarious, and the new Republic, under the presidency of Emilio Castelar, had decreed compulsory military service for all its able-bodied young men. So Cajal became a regular recruit, living in barracks, eating in mess halls, and trying to adapt himself to the rigid routine of army life.

In the hope of getting a commission if he passed the examinations then being held in Madrid for assistant physicians in the medical corps, he set off for the capital after months of study by which he had prepared himself for the tests as best he could. His diligence almost caused him to fail. Worn out with overwork and loss of rest, he overslept on the day of the written examination and arrived an hour late at the Military Hospital in the Calle de la Princesa. Only by adroit diplomacy did he gain admission to the examination room at all, and when he did get in, he found the others so absorbed in their work that no one paid any attention to him. He squeezed in at the corner of a table, snatched some paper to write on, and lost himself in a discussion of cholera, the subject that had been assigned. But he had hardly more than begun when the allotted time was over.

dations in the Catalan cities, but the peacefulness of the war was far from satisfying to Santiago, who longed for the excitement of actual combat. The cautious campaign did build up his health, which had been sorely tried by the strenuous work of recent months, and his many contacts with the peasants and townspeople taught him to know the liberty-loving natives of Cataluña through and through

Once he thought he was really going to get a taste of war. The regiment was spending the night at Tárrega when reveille sounded just before dawn. The men rose wearily to undertake a march of more than fourteen leagues. They finally arrived, exhausted, at Manresa, Santiago suffering doubly from fatigue and from the cuts his new boots had caused him. The next day the soldiers marched on to Sallent and then to Berga, where they pitched their tents. From moment to moment they expected to be attacked at ambush in the gorges of the Llobregat. But the insurgents, perhaps knowing of the considerable force sent out to waylay them, failed to put in an appearance, and the only warlike exploit Santiago had to relate was that of spending a night in a camp in the mountains and getting a bad cold from the night dew.

His wanderings through Cataluña after an invisible foe eventually came to an end. He was drawn by lot for service with the expeditionary force to Cuba. The war of Cuban independence, which had been waged intermittently since 1868, had flared up again and Spain had to send a new corps of physicians to the island to replace those who had lost their lives there. Going to Cuba meant Cajal's promotion from lieutenant to First Medical Aide, a rank equivalent to a captaincy, and this was, of course, gratifying to his ambition. He rather sadly took his leave of the peasants of Cataluña, whom he had come to like and respect, and of his regiment, in which he had made some good friends. He felt no resentment that, by a mere trick of chance, he had to undertake this thankless journey. Quite the contrary. He was overjoyed at his luck in get-

[60]

ting this opportunity to serve his country and at the same time to have adventures in the New World

Before going home for his final leave, he paid a visit to the capital of Cataluña, Barcelona, to get a view of the ocean—which he had never seen before and on which he would be sailing in eighteen short days—then on to Zaragoza to bid goodbye to family and friends. Don Justo was annoyed by Santiago's eagerness to be off, and urged him to apply for a discharge, being deeply concerned about the danger of illness in Cuba, as well as the hazards of war, and emphasizing the point that his son's future lay in medicine and not in military advancement. But Santiago had always been able to match Don Justo's stubbornness with his own. He answered that he would consider it a disgrace to apply for a discharge but promised that when the campaign was over he would return to his work in anatomy. To be honest, it was his longing for new experience as well as his patriotism and his sense of duty that prompted him to brush aside his father's wise solicitude.

At this moment rebellion struck the Cajal family from an unexpected source. Pedro, two years younger than Santiago, embarked first on an enterprise so much more spectacular than the one to which his brother was assigned as to dwarf Santiago's adventure. At eighteen, Pedro had fled from the University of Zaragoza, gone to Burdeos, and set sail for Uruguay, where he was destined to go through a long series of vicissitudes. He became a soldier of the pampas, was wounded in several battles, and finally was made secretary to an Indian chief who was something of a military genius though he could neither read nor write. Not until eight years later did Pedro return home to resume his studies at the medical school.

With Pedro gone, there was no one to share Santiago's excitement at the prospect of going overseas but his classmate and fellow soldier Cenarro. Even before the two boys had joined the army, they had taken walks together along the Paseo de los Ruiseñores, full of talk of the military exploits they hoped lay in store for them.

Explorer of the Human Brain

Both saw in the army a chance to visit distant lands, lands with magic for them in their very names—the Philippines, Puerto Rico, Cuba, Africa. Both were tired of the monotonous grind of school life, thirsting for freedom and new emotional outlets. Santiago's Mecca was America, chiefly tropical America, of which he had read lush descriptions in the French and Spanish romantic poets and novelists who had exerted such power over his youthful imagination. He saw it in the colors painted by Chateaubriand—virgin forests, brilliant blue seas, flaming flowers of rare hues and heady fragrances. Each of these young men was destined to have full satisfaction of his longing for adventure. Cenarro became an army surgeon and was appointed to the Spanish embassy at Tangier. As for Santiago—

Before two years had passed [he says] I found myself shut up in that much admired West Indian jungle, in those shadowy glades as sad and gloomy in reality as they were seductive in the descriptions of Bernardin de Saint-Pierre.¹ Those who have sung the praises of the tropics have overlooked one single small detail—that enchanting Paradise is simply uninhabitable for a European.

NEW WORLDS TO CONQUER

DON JUSTO resigned himself to the inevitable. In order to do the best he could for his son, he procured letters of introduction for him to the Captain-General and to other persons of importance in Cuba, in the hope that through them Santiago would be stationed at some reasonably healthful post. Armed with his letters, Cajal proceeded to Cadiz, where, joined by several companions, he embarked on the little steamer *España*.

The sea was smooth, and there was much recreation on board, both the organized entertainment provided by the *Compañía*

¹ Bernardin de Saint-Pierre (1737-1814) French writer, author of *Paul et Virginie*, etc.

Transatlántica and that devised by the soldiers themselves Santiago spent most of the time on deck, watching, spellbound, the surging sea, the flight of gulls, the leaping of the flying fish, and the shifting constellations in the sky at night

Even in the black swell (the black sea of Homer) there were fascinating surprises [he wrote] On calm nights the water did not merely reflect the light of the sky but glowed with a mysterious refulgence of its own My childish curiosity delighted in tracing the phosphorescent wake of the swarms of *noculucas*, excited by the formidable disturbance made by our propeller I was a little afraid, feeling as if I were floating between two infinities I still had fresh in mind what I had read in the writings of the evolutionists, who look upon the sea as the cradle of life and the rhythm of the waves evoked in me the throbbing love of the mother embracing her children (It is true I had not seen the goddess *Thetis* in her more murderous moods)

On the seventeenth day of the journey he caught a glimpse of the city of San Juan de Puerto Rico, glistening in the early morning sun He thought it a wonderful sight—on the left, the great hulk of Morro Castle, bristling with cannon, and on the right, an endless array of palaces and villas, intertwined with rows of palm trees Havana, reached soon after, seemed to him for all the world like a city in Andalusia, which made him feel at home at once The architecture of the little, two-story houses, each with its patio and secluded garden, was familiar, even the speech of the people reminded him of the South of Spain And the Creole spirit that pervaded the whole—the languor and indolence mingled with sensitiveness and grace—was Andalusian too Though he responded keenly to the charm of the place and its people, he felt, in his more practical moods, that it would have been better if the Spanish colonies in America had been settled by the sturdier, more disciplined stock of the northern provinces, a stock more fitted by nature for the struggles of commerce and industry

In Havana, far from being disappointed in the reality of a city he had pictured so glowingly in anticipation, he was at first en-

Explorer of the Human Brain

chanted by everything. He loved the mixture of races met with in the streets, the vivid flowers in the parks, the violent sun, the savage rain, the Spanish moss enshrouding trees and iron balconies—it all suggested a weird stage setting or something from the saturnine imaginings of a Poe. But he did not find the virgin forests so widely advertised by the Romanticists. Instead of endless jungle dark with trees a thousand years old, there were around Havana only scrubby thickets and a disorderly array of small cedars and mahogany trees. If only he could have set foot in this land with Columbus, he thought, before the rough-hewing of colonization had desecrated it! As the weeks went by and he explored the countryside, he found that animal life was far from abundant, and he deplored the virtual extinction of the native races. The Creoles, on closer acquaintance, impressed him as a lazy lot, living on the sweat of the Negroes and contributing little to the sharply stratified society of which they considered themselves the flower. By what he saw of them he became convinced that the white man deteriorates in a tropical climate. Only the Cuban women seemed to him to have escaped the degenerating influence of the indolent life, they were all grace, exquisite in face and figure, their soft voices like a caress. (Which perhaps explains why most of the Spanish soldiers promptly fell in love with these engaging beauties.)

A month after their arrival in Cuba, the medical officers were assembled in the quarantine station and told of the vacancies they had been brought over to fill. Cajal's pride forbade his presenting the letters of recommendation his father had obtained for him, though most of his colleagues used every scrap of influence they had in an effort to get the hospital appointments, which were known to be sinecures. These were soon all given out and the doctors without important friends were assigned to the regiments or to the infirmaries in the jungle, remote outposts where supplies were scarce and conditions appallingly unhealthful. The regimental physicians fared a bit better than the infirmary doctors, in

[64]

spite of their more direct contact with actual fighting, they at least drew their pay regularly and had the chance occasionally to return to the city for recuperation and social life.

VISTA HERMOSA

CAJAL was assigned to direct one of the worst and most isolated of the infirmaries—Vista Hermosa—situated in the jungle in the district of Puerto Principe, a region devastated by war. A few days after getting his orders, he set sail in the steamer allocated to this mission, accompanied by several other doctors and a body of fresh troops sent to replace recent casualties. An armored train conveyed them in a few hours from Nuevitas to Camaguey, from which, after a few days' respite, Santiago went on to Vista Hermosa.

It was while he was on his journey to this destination that he learned of the imminent restoration of the monarchy in Spain. He was taking coffee with some other officers one day when a major from Aragon startled him with this question:

"You have just come from Spain. What is the news about the conspiracy that is supposed to put Don Alfonso on the throne?"

Santiago mumbled, "I think Castelar's Republic deserves the confidence of the army."

"I see, old man, that you've been living out of this world. Don't you know that the army is monarchist 100 per cent, and that sooner or later the Republic will go down?"

Cajal was dumbfounded, but the major's prediction was soon to be fulfilled.

Back in Spain, General Pavía, after putting down the revolt of the Carlists in the North, had urged President Castelar to take over the Government by a coup d'état, such as that which many years before had made Louis Napoleon the Emperor Napoleon III. But Castelar was a sincere Republican and refused to do this. Yet in spite of his wisdom, his good government, his democratic prin-

Explorer of the Human Brain

ciples, and his honest effort to reap the fruits of the Revolution and to establish the Republic on a permanent, orderly basis, Castelar was destined to fail. Several mutinies that had occurred in the army had alienated the loyalty of the officers and of the middle classes. Soon he was defeated in the Cortes, and General Pavia took over for a time, toying with the thought of seizing the Government himself, but finally turning over control to Serrano, who tried to rule along the conservative lines he had always championed.

With this change in the leadership of the Republic, the Carlists stirred up trouble again and Serrano's first task was to send out another army to suppress them. Meanwhile, the enthusiasm that had ushered in the new state was changing into smoldering discontent and impatience at the course affairs were taking. The people were growing weary of the anarchy and the constant warfare that accompanied republicanism and with which it had become inextricably associated in their minds. They wanted peace with security and cared little now whether it was to be obtained from Carlos or from Alfonso, son of the once-hated Isabel, they were convinced that it was not to be had from the men now directing the policies of the nation.

When by the end of the year the Carlists had exhausted their strength in fighting Serrano's troops, the followers of Alfonso took up the battle against the established Government. On December 29, 1874, Alfonso XII was proclaimed king at Sagunto. The troops stationed in that part of the country offered no opposition. The Government leaders did put up a feeble resistance, but when the garrison of Madrid declared itself for Alfonso, they gave up the struggle. The Cabinet resigned and President Serrano left the country. Alfonso was in Paris when his followers accomplished this signal victory in his behalf, but a few days later, on January 14, 1875, he entered the capital.

Meanwhile Cajal, quite out of harmony with this turn of events, was burned alive at Vista Hermosa. This small encampment [66]

sprawled out over gentle slopes completely surrounded by jungle. On the highest of the little hills there was a square log fort, pierced with loopholes, in it a small company, its numbers much reduced by illness, was stationed under the command of a captain. The hospital stood a short distance away, a crude, shedlike structure with a thatched roof, flanked by two towers and reinforced with a parapet of logs. The fort and the hospital were the only buildings of any consequence on the premises. Beyond them on the slopes were a few shops and the miserable huts of the Chinese and Negro laborers. Once a month rations were brought up by active troops. Otherwise the dwellers in this outpost were cut off from the world, not daring to venture a mile into the jungle for fear of the insurgents who were lying in wait there. Constant minor skirmishes took place between them and the sentries.

The infirmary had more than its quota of patients, for approximately two hundred were bedridden with malaria or dysentery. Cajal slept close to them in a little room separated only by a partition of boards. Besides a bed and a table, his room contained muskets, cartridge crates, and boxes of biscuit, sugar, and medicine—chiefly sulfate of quinine. In one corner he fixed up a tiny photographic laboratory, using wooden boxes and empty cans, and he built a bookcase for his small library. In what leisure he had he amused himself with reading, drawing, and photography. But, as he says, against microbes neither art nor flights of fancy offer any protection. Soon he too was a victim of malaria, and no wonder, for they all lived amid swarms of mosquitoes, roaches, gnats, and other forms of insect torment. If the medical men of the period had even suspected that malaria is transmitted by mosquitoes, thousands of Spanish lives could have been saved in this Cuban campaign. But no one suspected it then. Enormous doses of quinine did little good because the patients were promptly reinfected from the original cause. The poor food did not help either. Cajal did his best to keep going but in time was prostrated by a combination of malaria and dysentery. His incompetent assistant

coped with the situation as well as he could and Santiago took advantage of his enforced idleness to study English! Although he was as ill as any of his patients, who were dying like flies around him, his youthful faith never allowed him for a moment to doubt his own survival. He was sure that as soon as he could get away from the miasmas of the swamps he would be well again, for at that time malaria was thought to be caused by the exhalations of the swampland, not the insects it nurtures.

As if this life were not wretched enough, one morning at day-break the rebels tried to make a surprise attack on the camp. Santiago was awakened by loud shouting and a volley of gunfire. He leaped from his bed and threw on his clothes. Through his window he saw a group of cavalymen and foot soldiers, mostly mulattoes and Negroes from the jungle. The commander prepared to defend the fort, offering its protection to Santiago. But Cajal refused to take refuge there, his duty lay with his patients. He seized a gun and ran through the wards, urging those who were not too desperately ill to join him in the defense of the infirmary. Most of the soldiers did take part, those too sick to stand knelt in their beds and fired through the windows. A few weeks before this, the insurgents had fired on a similar settlement, Cascorro, and had massacred guards and patients, but this time, finding the garrison at Vista Hermosa forewarned, they withdrew without attacking.

After this incident Santiago became so ill that he was forced to apply to the Inspector of Health at Puerto Príncipe for a month's leave. As there was no one to take his place, this was difficult to obtain, but he finally did get leave and went to Camaguey for treatment, by which his health was greatly benefited. But he was never afterward to be entirely free of the far-reaching effects of the type of malaria to which he had succumbed.

Because of the condition of Cajal's health after four months of Vista Hermosa, Dr. Grau, then Head of the Department of Health, transferred him temporarily to duty as physician at the military hospital of Puerto Príncipe. While in this position he made friends

among the other young doctors who like himself had recently come over from Spain, and he came to know the outstanding surgeon, Dr Ledesma, Director of the Army Medical Service and later physician to the royal house of Spain. His period of convalescence in Puerto Príncipe, which lasted only six weeks, he later looked back upon as the pleasantest part of his sojourn in Cuba. There was much social life in the city—lavish parties, gay evenings in the cafés, reckless gambling in the casinos. This led to great dissipation among the officers and men—alcoholism, gambling, and promiscuity—all of which Santiago had sufficient character to resist, although many a good soldier in the Cuba of the time fell victim to one or another of the three. Many of them were practically driven to gambling, since it was quite usual to have one's pay withheld for months, and as a result of this laxity on the part of the officials the soldiers were in a state of continuous financial collapse. Cajal himself after four months in Cuba had received only his first month's pay, 125 gold pesos. The poorer one's position in the service, the less likely was he to be paid at all. The doctors assigned to the city posts got along fairly well, but those relegated to the distant infirmaries were practically forsaken. The economic distress of the physicians in the outposts was due not only to characteristic mismanagement on the part of the authorities but also to the absconding of a certain Villaluenga, pharmacist in the military hospital at Havana and paymaster general of the medical corps, who fled to the United States at about this time with a woman of ill repute and the sum of 90,000 pesos.

Cajal grew so impoverished that he had to call upon Dr Grau for help. Dr Grau did sponsor a loan of 125 pesos for him, levied on his colleagues. But Cajal's asking for a loan earned him unpopularity among his fellow officers, who thought he should depend on credit as they did and give up his exaggerated scruples. They did not take into account the fact that he had been living in an uninhabited region in which there was no one able to extend credit, and that for part of his stay there he had been too

ill to seek out any even if there had been any to be found And while he was in the city, what merchant would be such a fool as to lend money to an unknown man who was so obviously sick that he might not live to pay it back? But the grudging advance that Dr Grau was able to collect had one important result besides saving Cajal from bankruptcy it made him vow never to ask for financial help from anyone again, a promise he kept all his life

SAN ISIDRO

CAJAL'S CONVALESCENCE now officially declared over, Dr Grau assigned him to the infirmary at San Isidro, whose medical director had just died in the line of duty, as had the director before him When Cajal got there, taking his place, as he says, in the queue of death, he found San Isidro to be even more unhealthful than Vista Hermosa Its only advantage was that it was more accessible, being on the East Military Road, which started at Bagá Between San Isidro and San Miguel de Núévitás a military train ran daily, hence the procuring of supplies was less of a problem The field hospital was little more than a huge shed with beds for three hundred patients Like the infirmary at Vista Hermosa, it was protected by a square fort armed with a garrison It was surrounded by swampland and had been selected as a penal hospital for dissipated military men Cajal gives us a picture of this Cuban Devil's Island

Soon after my arrival I saw how effective a place of expiation this was A certain drunken, quarrelsome officer had just died there and two other officers who had just filled out their terms at San Isidro were boarding the train to freedom with weak steps and haggard faces A few days later, a captain of the headquarters staff arrived This fellow was half crazy but he was also very clever, and I had animated conversations with him and with three other officers from different parts of the service, who had been accused of scandals and of commit-

ting inexcusable excesses in cafés and other places of amusement. They were cheerful, talkative fellows. I passed the time not too unpleasantly listening to the tales of their escapades. Such conquests in the lists of love! Such ingenious tricks to get around the watchfulness of husbands and fathers! Such stratagems to open the coffers of the money lenders!

The distressing thing was that these entertaining chats soon stopped. In one or two weeks almost all these arrogant Lovelaces had succumbed to fever. And when the hour of their longed for deliverance struck, they rose from their beds determined not to spend another day at San Isidro. Two of them were carried to the train on stretchers. I remember that when they said goodbye to me they looked at me with pity in their eyes, such looks as the ransomed of Argel² must have cast on the captives who had no hope of release.

From the Spanish point of view, the campaign in Cuba was to prove a dismal fiasco. Part of its failure was due to the strategists who had planned to cut the island into three parts through the construction and defense of military roads, called *trochas*. These highways were lined with strong palisades and sometimes fortified with barbed wire entanglements, defended by a blockhouse every five hundred meters. Every thousand meters or so, there was a wooden fort with a larger company of soldiers. The settlements along the roads were guarded by the army, too, and offered some measure of safety to hospitals and stores of ammunition.

Cuba has roughly the shape of a sausage divided into three sections. The rebellion had been most active in the east. The plan behind the fortified roads was to cut the island from north to south and thus to divide it into tight compartments to prevent the spread of the insurrection. The roads were to keep the western and central regions, source of army supplies, from the contagion of the eastern, by sealing off the two more peaceful sections, it was thought that a relatively small army could put down the revolt. But these supposedly impregnable roads were not all that was claimed for them.

² The Moorish stronghold in which Cervantes was imprisoned for five years.

Explorer of the Human Brain

They were crossed constantly by rebel bands without undue risk. They made slow-moving and unwieldy an army that would have been far more effective in guerrilla warfare. They were costly to maintain, a catastrophic fact in view of the desperate financial straits through which Spain was then passing as a result of almost continuous civil wars. Worst of all was their toll in human lives: they immeasurably increased the amount of sickness because many of the forts guarding the military roads, like that protecting the hospital to which Cajal was assigned, were located in swampland. Cajal estimated that the roads caused the death of 20,000 men before their use was abandoned. Deploring in his later years the disregard for human life that is inseparable from war, he cried out in protest: "It is amazing and infuriating to see the blindness and the stubbornness of our military leaders and governors, and the unbelievable lack of feeling with which they have always squandered the blood of the people! How it distresses one to think of the complete irresponsibility our blundering generals and egotistical ministers have been guilty of!"

It was because of such unintelligent strategy and such fundamental weaknesses in the character of the Spanish leaders, both political and military, that Cuba would later win her freedom from Spain. In the light of history and of powerful trends operating in all the countries of the Americas, even as early as 1875, Cuban independence was inevitable. Yet to forestall this—or even in the vain hope of preventing it altogether—Spain bled herself dry, following the policy of her Conservatives, who had pledged to this attempt "the last man and the last peseta." As a colonial power Spain could have profited by the example of England, which, having learned its lesson from the American Revolution, had become astute enough to grant her remaining colonies a wide margin of autonomy. If the Spanish leaders had been as attentive to the lesson to be learned from this Cuban war, the later clash with the United States might have been avoided.

Though half-sensing the futility of the whole enterprise, Cajal

struggled on from day to day with the heavy burden of his medical duties at San Isidro. At all times his hospital contained three hundred patients or thereabouts, men ill with smallpox, ulcers, malaria, and dysentery. A difficulty almost greater than that of caring for them was the effort to keep the employees of the hospital from stealing everything they could lay their hands on. Bribery and corruption were the order of the day from the commander of the guard down to the humblest manual laborer. The patients were not being fed even as well as the modest provisions allowed them should have permitted, since the officers and the cook somehow managed to spirit away all the good food, leaving nothing for the sick men but refuse devoid of sustenance. When Cajal confronted the offending officers and the cook with this accusation, he was given the short answer that his predecessor had got along well at San Isidro because he had overlooked such things, and if Dr. Cajal knew what was best for him, he would do the same. The black market was flourishing, too, and cook and officers were not only well fed but also rich from the money their under-cover traffic brought them. Cajal, meanwhile, was still desperately waiting for an installment of his pay, always interminably delayed.

A clash with the major, who, as officer in charge of the garrison, really carried the responsibility for the state of things at San Isidro, was inevitable. Cajal accused him of failing in his duty in not seeing to it, and at once, that conditions were changed. He threatened that if the major did not take steps in this direction, he (Cajal) would rectify the abuses himself. Though angry, the major neither denied the facts nor promised to alter them. So Cajal proceeded to carry out his threat, taking the first step toward reform by having the orders for provisions carefully checked each day with the items received. The response was immediate and violent. Cajal was cut by all his fellow officers and every petty annoyance they could think of was inflicted upon him. All this while he was visibly wasting away from a new attack of malaria.

One of the things the major did to humiliate him was to stall

two of his horses in the hospital with the patients, pretending that he had no room for them in the fort and dared not leave them outside lest the rebels steal them. Cajal was in bed with fever when he heard the horses' hoofbeats on the floor outside his room. He got up in a fury, went out to where the grooms were tying up the horses, and drove both grooms and horses out of the building. The commander stormed in, quivering with rage.

"How dare you disobey me? I am in command here!"

"I beg your pardon," Cajal replied. "Inside this hospital there is no authority above mine. I am responsible for the care of my patients and I will not have the hospital turned into a filthy stable."

The other officers finally succeeded in pacifying them both. The commander drew up an indictment against Cajal for insubordination, even threatening to have him thrown into prison. But eventually, when through Cajal's disclosures of the sharp practice and the black marketing going on at San Isidro, the actual conditions became known to those in authority in Puerto Príncipe, the whole affair quieted down, the incumbents thinking it the part of discretion to let well enough alone. So there was no more talk of proceedings against Cajal, though the major made life as miserable for him as he dared.

Cajal saw strange things at San Isidro—things he was never afterward to forget: the wild merrymaking of African Negroes brought over to Cuba on slave ships, dances half-naked under a brazen sun to the beating of tom-toms, the shrill chanting of weird jungle songs. They would dance for nine or ten hours at a stretch in a sort of intoxicated frenzy. Far different were the harp concerts of the strolling Italian vagrants, simple souls who had been seized while drunk in taverns in Spain and shipped out to Cuba as soldiers in the Spanish army. One such Italian came to Cajal's hospital stricken with dropsy, jaundice, and malaria. Ill though he was, he kept constant watch over his harp to be sure it was not stolen from him. When he had partly recovered, he would sit in the moonlight, a pathetic, grotesque figure, leaning against the

trunk of a tree and playing, for the pleasure of the other patients and for the pennies they would throw him, arias of Rossini and Donizetti and wistful ballads of his native Savoy.

Cajal spent six or seven months at San Isidro, trying to do his work while almost at death's door. His malaria was shortly complicated by dropsy. Dr. Grau, to whom he had now applied for a transfer, had to all purposes abandoned him, telling him to hold on as long as he could until someone could be found to take his place. As time went on, Cajal saw there was no hope of help from that source. So he decided to ask for an honorable discharge because of ill health. He sent in his request to the Captain-General through the health authorities of Puerto Príncipe. But, as he later learned, Dr. Grau *did not send on his petition to the final authority* but left him to drag out his existence at San Isidro as long as his body would stand it.

RELEASE AT LAST

CAJAL owed his life to a chance occurrence. At last the military roads were being suspected to be the plague spots they were, and the authorities decided to investigate them and also to make a survey of conditions at the outpost forts and infirmaries. A certain brigadier who came to San Isidro on this mission took on himself the responsibility of seeing that Cajal's request for discharge was forwarded to the proper person. Presently the Bagá military road was abandoned, and all the patients formerly under Cajal's care (with Cajal among them now) were sent to the hospital at San Miguel. This was another wretched building assigned to sick officers and directed with the usual inefficiency. Conditions were so bad there that one hot-tempered officer in a bed near Cajal, maddened with thirst and getting no response from the over-worked sister of charity, began using his revolver to summon her. Cajal got out of his own bed and attended to him.

Explorer of the Human Brain

At length he was well enough to take the trip to Puerto Príncipe. His petition had finally gone through but he had to undergo a physical examination before getting his honorable discharge. His illness was diagnosed as acute malaria, and preliminary orders for his release were issued under date of May 15, 1875. He set out for Havana, where he was to get his pay, his passport, and steamer passage to Spain. Several months of back pay were due and there was every likelihood that he would have to spend as many months in trying to collect it. He had anticipated such a situation and had written to his father to ask him for money. Don Justo quickly sent some on to him. Fortified by it, Cajal put up a fight to get his pay and finally succeeded, deducting from it the 40 per cent commission demanded by the minor official who had helped him. The remainder was enough to clear up some small debts he had been forced to run up and to pay for his passage, with a bit left over. At last he boarded the steamer for Spain, his once robust health undermined and his idealism badly shattered by this Cuban adventure.

Besides relieving the misery of many victims of this mismanaged campaign, he did reduce the corruption of one outpost station to a minimum before leaving it forever. He took home with him the shreds of his disenchantment about the glamour of war and a bitter realization of the low estate to which patriotism and common decency had fallen among certain groups of his countrymen.

5. "Poor Ramón Is Lost for Good"

Who can find a virtuous woman? For her price is far above rubies The heart of her husband doth safely trust in her, so that he shall have no need of spoil She will do him good and not evil all the days of her life Her children arise up, and call her blessed, her husband also, and he praiseth her Many daughters have done virtuously, but thou excellest them all

—PROVERBS OF SOLOMON, 31 10-29

EMBARKED at last for Spain, Santiago settled down to the task of getting well At the last minute before starting on the homeward journey he had been stricken with a new attack of dysentery and was filled with despair at the prospect of being left behind in Havana He had rallied just in time to be spared this ultimate misery The sea air and the thought that he would soon be with his family and friends did much to hasten his recovery By the time the *España* reached Santander, he was practically a new man, with a ravenous appetite, and strong enough to enjoy the life on ship-board as much, or nearly so, as he had on the way out

He had some amusing adventures on the trip and was witness to robust rogueries in the old Spanish picaresque tradition, for he shared his stateroom with a professional gambler This man was one of a group of "sharpers" who spent their lives commuting between Spain and Cuba, doing a thriving business on the return trip emptying the pockets of Spaniards who had grown rich in

Explorer of the Human Brain

America and were now coming back to dazzle the folks at home. Some of them lost in a few hours the money earned by years of toil, savings squeezed from the rigid economies they had practiced while making their way in the New World. One fellow who had gambled away more than \$15,000 had to have his friends pay his boat fare on the small vessel that took him ashore when he reached Spain.

The steamer arrived at Santander on June 16, 1875. Cajal was enchanted by the beauty of this seaside town, which he found in many ways reminiscent of the luxuriance and the exotic charm of Cuba, and he explored it thoroughly. On his way to Madrid he stopped over at Burgos to see the cathedral. After a few days' rest in Madrid, still yellow and thin but feeling better than he had in months, he went on to Zaragoza, his heart bursting with happiness. Once at home, his health improved steadily in the good air and under his mother's loving care.

LOST LOVE

ONE of the first things he did upon returning home was to go to see a sweetheart he had in Zaragoza, an orphan girl whose letters had brought him a measure of sad comfort during the attrition of the Cuban days. She received him kindly but without the enthusiasm he had expected after their loving correspondence. He did not know what to make of it. It was true that as a result of his adventure in Cuba he had lost, for a time, both his health and his career. Though a physician he had no patients and, at the moment, had not strength enough to perform the rigorous duties that usually fall to the lot of the poor country doctor. He had yet to try to think his way out of the economic dilemma in which he now found himself. He certainly was no great catch—was that the reason for her coldness? Had she another suitor, perhaps? Or was she really still in love but felt herself constrained by convention

[78]

to keep her affection hidden until he was in a position to make a definite offer? He decided he could not bear the uncertainty. Words can deceive but expressions do not, he told himself on thinking the whole matter over, and he settled on a risky experiment by which he was sure he would find out the truth. He would kiss her unexpectedly and see how she reacted! He was well aware of the limitations of the timid kiss on the cheek, but it was all he dared consider at this point (never yet having kissed a woman though he was now twenty-four years old) and he could think of no better catalyst to love that he felt himself capable of. Inexperienced as he was, and knowing the extreme modesty of his *novia*, he was filled with misgivings. Still it had to be. One evening after a drooping conversation that had been painful for them both even to try to keep up—they seemed now to have nothing to say to each other—he took leave of her for the night. Summoning all his courage before he turned to go, he kissed her brusquely on the cheek. Amazed and indignant, she drew her head back with a cry, and—what was more revealing to Santiago—with an expression of intense repugnance in her eyes.

"I never expected you to offend me so!" she exclaimed. "You know I do not allow such sinful liberties. Do you take me for the sort of girl you might pick up in a café?"

Santiago was overwhelmed with shame. He mumbled an apology and fled. But his test had been successful. It told him what he had to know: to this girl he seemed nothing but a poor invalid, and an ill-mannered one besides. She did not love him, perhaps she never had. A girl who was well brought up and discreet but in love would have found kinder, more indulgent words with which to reproach the impetuosity of a lover. But as he was to learn afterward, the girl had been appalled by the change in him since his return from Cuba, and the prospect of being left a widow—for she was sure he was on the brink of the grave—did not have much allure for her. So Cuba had robbed him of this youthful

Explorer of the Human Brain

love, too, for whatever it might have been worth. It became a sort of sacrifice on the altar of his boyish recklessness.

CARVING A CAREER

SANTIAGO'S was a nature too deep and too intense not to suffer from a blow like this one. It embittered him a little about betrothals. Decidedly, he felt, they were not for him. But the economic problem he faced at the moment was pressing and could not be pushed aside even in such an emotional crisis as this. He had to draw up a plan for his future and embark upon it, and at once. So he followed his father's advice and went back to his study of anatomy and histology at Zaragoza in order to prepare himself for the competitive examinations regularly held in Spain for professorships in the various universities.

Fortune had not altogether forsaken him. While he was pursuing this course he was appointed temporary assistant in anatomy, with a salary of 1,000 pesetas (less than \$200) a year. Two years later, he became temporary auxiliary professor, an opening that arose because the Faculty of Medicine of the University of Zaragoza was being reorganized and the duties imposed on all the teaching staff were unusually heavy. From the increased salary that came to him as a result of this appointment and the money he earned from private tutoring, he became partly independent of his father.

His hopes and aspirations now ran high, his health improved, it looked as if, in spite of his shy and retiring nature, life might hold something of brilliance for him after all.

I aspired to be something, to emerge from the plane of mediocrity, and to collaborate, if my powers permitted, in the great work of scientific investigation that I hoped might bring some measure of glory to my sad country. Resolute in this patriotic desire—which all my colleagues considered pure insanity if not pompous pretentiousness—I



*Above, CAJAL'S FATHER WHEN
PAST SEVENTY Right, CAJAL'S
MOTHER AT THE SAME PERIOD*

*(Courtes) of Dr E Horne
Craigie, Professor of Compara-
tive Anatomy and Neurology,
University of Toronto, Canada)*



Above, CAJAL IN 1884 AT THE
TIME OF HIS APPOINTMENT TO
THE UNIVERSITY OF VALENCIA
Right, CAJAL'S WIFE A YEAR
BEFORE HER MARRIAGE

(Courtesy of Dr E Horne
Craigie, Professor of Compara-
tive Anatomy and Neurology,
University of Toronto, Canada)



worked to obtain the modest living and the uninterrupted leisure indispensable to the projects I had at heart For me the means to this end were to be found in the honorable gown of the schoolmaster

With Santiago in this humble role, the year 1876 and the first months of 1877 passed uneventfully He substituted for his father at the hospital when need arose, in addition to continuing his studies and his teaching He was not particularly eager to take the doctor's degree, but his father kept at him until he completed his preparation Santiago realized too late that it would have been wise if he had done his work in the history of medicine, chemical analysis, and pathological histology at the University of Madrid This would have made it possible for him to meet the leaders in these fields in Spain, men who would later be his judges in competitive examinations for positions and even now in the final oral examination for the doctorate But, instead, he carried on his study at home in Zaragoza, following the prospectuses of the courses at Madrid as well as he could He had to manage the history of medicine and pathological histology alone, since there was no one in Zaragoza capable of instructing him in these He did have a tutor in chemical analysis—a capable pharmacist, Don Ramón Ríos, head of a factory of chemical products

When in June, 1877, Santiago arrived in Madrid to take the examinations for which he had been preparing, he found that much of his time and effort had been wasted From talking with candidates more closely in touch with the way things were done in the capital, he learned that only the simplest questions would be asked in the field of chemical analysis, such questions as the composition of milk, urine, and blood, which any well-qualified student would know even without making an intensive study of the subject. (Chemical analysis, incidentally, was held in some contempt by the leading professors of the day) Similarly, Cajal had learned a great deal more than he needed to in the history of medicine Instead of basing the questions in this branch of medical knowledge on the French text that was ordinarily regarded as the

classic in the field, the professor who made up the examination would base them on a simple booklet unknown to Santiago but well known to the students of the University of Madrid. Only the professor of histology gave his course as it was announced in the catalogue, basing it on the standard textbooks generally recognized as the outstanding ones to be consulted.

Faced with this situation, Santiago spent four hectic days before the examinations officially opened in an effort to cram into his head as much as he could of the special information known to the initiated in the capital—Dr. Ríos' lyrical descriptions in chemical analysis, and Dr. Santero's treatise on the history of medicine, a text presenting a highly partisan, vitalistic interpretation of events. As a result of the torture through which he put himself in his eleventh-hour skirmish to make his thinking conform with the teaching of Madrid, he managed somehow to say the approved things.

CAJAL DISCOVERS THE MICROSCOPE

THE ORDEAL had one favorable outcome besides giving him the degree he sought. Some professors in Madrid showed him some fine microscopic preparations, and he became fascinated with microscopy, resolving to set up a tiny microscopic laboratory as soon as he returned to Zaragoza. This was not easy for him to do. In spite of all his brilliant work in histology, he had never up to this time seen microscopic preparations made and had never been taught how to carry out the simplest procedures. And there was no one in Zaragoza to teach him. Moreover, the Faculty of Medicine of the University of Zaragoza almost totally lacked the necessary equipment for such an undertaking. He did manage to find in the physiology laboratory an ancient microscope in fairly good condition, and it was through this venerable instrument that he first beheld the amazing spectacle of the circulation of the blood.

He found an old attic that would serve as the setting for his laboratory and stocked it with a few of the standard reagents. But how was he to get a really good microscope? There was not enough left of his pay from the Cuban expedition to warrant such a financial plunge. All of a sudden one day he remembered seeing in Madrid in the Calle de León the shop of a Don Francisco Chenel, dealer in medical instruments, from whom one could buy a good microscope on the installment plan. So he wrote at once to Don Francisco and arranged to pay the sum of \$140 in four equal installments. This covered the cost of the Verick instrument then in vogue, with its accessories. Cajal's was the first good microscope at the University of Zaragoza. Later he would buy additional equipment, and eventually he contrived to make his attic laboratory a fairly workmanlike place. The cost of the new equipment came from his meager current salary, but for the laboratory itself and the small medical library he built up he used what was left of his Cuban money. So, he says wryly, his malaria was a blessing turned inside out. If he had not been ill in Cuba, he would have spent his money there instead of saving it and his scientific education would have gone to the dogs.

Naturally during my honeymoon with the microscope [he says] I did nothing but satisfy my curiosity. I had no method but examined everything superficially. A marvelous field of exploration opened up before me, full of thrilling experiences. A fascinated spectator, I examined the red blood corpuscles, the cells of the skin, the muscle fibers, the nerve fibers, pausing here and there to draw or photograph the more intriguing scenes in the life of the infinitely small.

One big item of expense was subscribing to the necessary scientific periodicals. Cajal did not then read German, in which the best articles on histology were written, so for lack of knowing that language he had to content himself with a French review. He read in French translation the works of all the great German investigators. He subscribed, too, to the English *Quarterly Journal of*

Explorer of the Human Brain

Microscopical Science More fully aware now of the problems still unsolved, he plunged into the solitary investigations that were soon to lead him far beyond the confines of his garret workroom

His chosen field, histology,¹ the study of the minute structure of animal tissue, was one to which the Spain of his day was frigidly indifferent when not openly hostile His guide through this labyrinth was the Spanish translation of the great Ranvier's² treatise on histological technique With it ever beside him to inspire and direct his investigations, Cajal wrote and published in 1880 the results of his first original research—two little pamphlets illustrated by lithographs he had engraved himself (He had no money to pay an artist) To make suitable pictures to accompany his articles, he invented a new process of reproduction and was probably the first in Spain to apply the art of photography to lithographic printing

These two publications, though of no great significance so far as their ultimate conclusions are concerned—Cajal was to modify his opinions progressively as his investigations continued—nevertheless did offer several minor contributions to histological knowledge The first paper was a study of inflammations, the second concerned the terminal endings of nerves in muscles In this second paper, he differentiated four varieties in the terminal branchings

¹ Histology (*histos*, tissue, *logia*, the study of) The term "tissue," which means "weave" or "texture," came into use in anatomy as a result of the work of the young French anatomist Bichat (1771-1802) While dissecting human bodies, he was struck by the various layers and structures he saw upon gross examination, which he observed were of different weaves and textures Bichat made the first classification of tissues and in this sense was the first histologist Though when the tissues of the body were later studied under the microscope, his classification was abandoned, his idea that the body is built up of layers of different composition is still valid, the microscope merely made it possible to classify these more accurately Histology is concerned not only with the structure and nature of the tissues, but also with the way they are arranged to form organs such as the kidney or the liver

² Louis Antoine Ranvier (1835-1922) French pathologist, professor at the Collège de France

of the motor nerves and made valuable improvements in the method then used for staining delicate nerve fibers so that they would stand out sharply when viewed under the microscope

Through the years the science of histology has developed many ways of treating tissue with chemicals so that the particular structures to be observed are clearly visible when the specimens are examined microscopically. The ideal of histological technique would be to prepare the sections in such a way that the tissue would differ as little as possible from tissue in the living state while still in the body, yet it must be differentiated enough to make the cells to be studied easily distinguishable from the surrounding material. Certain chemicals, when applied to fresh tissue, have such a selective action, coloring some cells and not others. Some stains will color only the nuclei of the cells, for example, others will color one type of cell but not other types, and so on. The perfect procedure has not yet been found, one method is better for one purpose, another for another, and there is much disagreement even today as to which is best for what, and new methods are frequently being devised.

Cajal's innovation consisted in toning the nerve fibers with gold chloride before impregnating them with the commonly used silver nitrate. He also discovered at this period how much more satisfactory ammoniacal silver nitrate is when applied to certain nerve fibers than silver nitrate that has not been previously treated with ammonia. In doing this he foreshadowed, unawares, the work that was to occupy him for a lifetime.

His small discoveries went unnoticed by the scientific world—inevitably, since his papers were written in Spanish, a language almost unknown outside his native country and Latin America. Besides, he could afford to publish only timid editions of one hundred copies, most of which were given to friends who had no special interest in the field. Even so, some of his colleagues expressed the opinion that he was presumptuous in setting himself up as an investigator and in daring to criticize the leaders in his

Explorer of the Human Brain

tology in the world outside, even implicitly by checking their conclusions with his own observations "Who is Cajal that he should question the foreign scientists?" they asked, in the tacit conviction that nothing good could come out of Spain

Far from being discouraged by this lack of recognition, Cajal felt his first attempts to be rewarding. They taught him technique, they taught him to know himself, with all his strengths and weaknesses as a researcher; and they taught him to understand the psychology of his fellow scientists—three highly important lessons.

In his later years he admitted that there was a certain amount of arrogance and presumption in his youthful enterprises, but he concludes his apology with a truth that a life rich in experience had taught him: without a certain lack of modesty nobody accomplishes anything important. Though in these years of his novitiate he did not feel himself to be especially brilliant, he did recognize in himself the humbler qualities called for by the task at hand: unending patience that was almost a kind of obstinacy in his determination to master histological technique, dexterity and skill, ingenuity in devising simple equipment and devices to replace the expensive ones he could not afford, tireless persistence, enthusiasm, intense interest, and an open-mindedness that enabled him to discard a cherished notion when it did not fit the observed facts. He soon found that work which his colleagues thought a bore had for him a perennial fascination. He once spent twenty hours continuously at his microscope, enthralled at watching the slow progress of a white corpuscle in its laborious effort to escape from a capillary.

How did his researches, though largely depriving him of social intercourse with his fellows, teach him to know so intimately the workings of the minds of other scientists in his field? This is how he explains it:

Nothing enables one to penetrate more deeply into the minds of other investigators than critically to compare their personal interpretations with the actual facts, following from close at hand the plan of action and the steps they followed to overcome the obstacles and snares

with which Nature seems to defend herself against human curiosity. In this careful comparison of the model and the copy, intellectual clarity, solid culture, technical difficulties, and sometimes the brilliant discovery of genius are revealed, but with these appear also the prejudices, inaccuracies, and mistakes of men of science. Once they are discovered, the little errors are very useful, for they encourage the beginner to persevere in his task and they spur him to greater effort. From my general check up on what the books had to say by my own direct observation of the facts themselves, I found that scientists—except in the rare case of really great minds—are human like everybody else without any advantage other than that of having prepared themselves adequately for research under the direction of illustrious teachers and in the warm greenhouse of the scientific schools.

The most valuable fruit of my effort at experimentation was the profound conviction that living nature, far from being drained and exhausted, keeps back from all of us great and small immeasurable stretches of unknown territory and that even in the realm seemingly most worked over many things are still to be cleared up.

With the new confidence that came to him, there came also sharp realization of his defects and the limitations imposed upon him by his environment. He was weak in physics and in the other natural sciences; he was not wholly conversant with all the discoveries that had already been made in histology, and he had very little material at hand in the library of the university to rectify these gaps in his knowledge. So he was forced, somewhat ruefully, to a further outlay of money with which to subscribe to other important histological reviews. To those to which he was already a subscriber he now added the *Journal de l'anatomie et de la physiologie*, a French publication which summarized the discoveries of French microscopists, and (now attempting German) the *Archiv für mikroskopische Anatomie und Entwicklungsgeschichte*, in which the contributions of German, Russian, and Scandinavian scientists were published, a magazine illustrated with colored lithographs and edited by the noted anatomist Waldeyer² of Ber-

² Wilhelm von Waldeyer (1836-1921) German anatomist

In He also purchased the monumental monographs of the French pathologist Ranvier

Finding microscopic investigation so exciting and so easy, he marveled that the professors of his time did not resort to it more often. Far from doing so, they even held the microscope in contempt, conceiving it as somehow detrimental to biological progress. Some of the more reactionary even declared the descriptions of cells and of other structures made by the microscopists to be pure fancy, "star-gazing." One Madrid professor, enlarging on this idea, called microscopic anatomy "celestial" anatomy—a derisive term that stuck, epitomizing the popular indictment of all microscopic study and reflecting the attitude of many learned men of the time. Even those more radical professors who did make use of the microscope and had respect for its revelations often lacked the curiosity and the diligence to check personally the findings described by the specialists in the field.

The Swiss histologist Kolliker⁴ used to tell an anecdote pointing up the indifference with which even the more progressive scholars regarded the microscope. In a letter to his family included in his autobiography, *Erinnerungen aus meinem Leben*, in describing a new museum of natural sciences, he wrote

I must tell you a story about the director, Graells. In his laboratory there is a splendid French microscope, and when I asked him if he had investigated anything with it, he said that he had not yet had a chance to apply it to his scientific work because he didn't understand how to work it. He asked me to show him how. So I showed him the corpuscles of the human blood and the striated muscle fibers. He watched the "show" with childish delight and thanked me most profusely.

In his own autobiography Cajal observes regretfully that if Kolliker had visited the medical colleges of Spain twenty years after

⁴ Albrecht von Kölliker (1817-1905) Embryologist and histologist, professor of anatomy at Würzburg. His work on histology was the first formal treatise on the subject.

this episode took place he would have seen the same apathy. There too the shining new microscopes stood untouched in their mahogany cases and were looked upon as mere museum pieces.

THE SLOUCH OF DISPOSD

IN THE midst of Cajal's discovery of microscopy, he heard that there were vacancies in anatomy at the universities of Granada and of Zaragoza. He hated the thought of halting the work that so absorbed him, in order to throw himself so soon again into an orgy of studying for examinations. Besides, he would have liked to inform himself fully about conditions in the two positions, to feel out what brand of knowledge was legal tender for each, before entering the lists again. But his father thought him capable of anything and practically forced him to take the tests without more ado. He did well in histology and anatomy (as was to be expected) but showed grave deficiencies in other respects, especially in the social graces. His natural timidity made him a poor speaker, tense and awkward, and his very honesty and lack of pomposity worked against him. His magnificent drawings on the blackboard on the occasion of his oral discourse did attract favorable attention, as did his detailed knowledge of descriptive anatomy. But that was all. The net result was failure. He returned home filled with the same emotions he had felt as a boy whenever he had disappointed his father's ambitions.

The year 1878 was to plunge him even deeper into a more personal grief. One afternoon while he was playing chess in the garden of the *Caf  de la Iberia* with a friend, Don Francisco Ledesma, a gifted lawyer, Cajal suddenly had a hemorrhage. He covered it up as well as he could and finished the game, and while he was on his way home the bleeding stopped abruptly. He said nothing about it to his family, ate as little supper as he could without causing comment, and went to bed. Soon he had another hemorrhage—

a terrible one this time, the blood foaming up in his mouth and almost choking him. He called his father Don Justo, though he tried to hide it, was thoroughly alarmed. The old malaria had never really left Santiago, and for months he had been pale and thin. A doctor cannot very well deceive himself about his own condition and Cajal was always one to face facts squarely. He knew very well how often tuberculosis follows an attack of malaria such as he had experienced in the tropics. Besides, his symptoms left no room for doubt—the high fever, the breathlessness, the hacking cough, the copious perspiration. He sank into a depth of melancholy that he had never reached even in the worst days in Cuba. He was already depressed by his failure in Madrid and this sudden catastrophe was too much for him to bear. The thought that his career was now over contributed a great deal to his gloom. This was the end then, of his hope that, somehow or other, humble doctor though he was, he would add something to the heritage of Spain. He felt that he had wasted the brief youth that was all he would have of life, wasted it on such trivialities as the romantic mouthings of Chateaubriand, Lamartine, Victor Hugo. He regretted the hours he had spent in poring over them, hours he now longed to give to enduring work.

Two months later, though he was at last able to get up and walk about, his outlook was no more cheerful. He thought to himself grimly, "This is only a reprieve. New attacks will come and then death." Religion might now have comforted him, but his study of philosophy had long ago deprived him of that solace. Two tenets had been salvaged—the belief that man has immortality of a sort and that a supreme power rules the universe. But he could not see love for man in such a power, and his proud spirit could not bend itself to accept a fate so unjust and so wasteful.

In these hours of idleness he reflected often on the meaning of life and death. It seemed fitting enough that the old should die with resignation and even serenity, they had lived their lives, made

their contribution, perhaps found their moment of fulfillment. Happy memories might sustain such a man to the end no matter what pain his aging body might inflict upon him, as they had sustained the Greek philosopher Epicurus, who spent his last days in tranquillity though a kidney stone was slowly eating away his life. But what had Cajal to console him—memories of the books he had not written, of the discoveries he had not made? In anguish, he considered the uselessness of all his life, the futility of the existence he was now dragging himself through day after day.

Don Justo was of tougher fiber. He believed his son could be cured. As soon as summer came, he sent him with his sister Paula to the baths at Panticosa to lie in the sun and drink the waters. There at picturesque San Juan de la Peña, with its moldering convent, now the home of shepherds, and its dark forest, Cajal's despair lifted a little, though at times he fell back into the abyss again. He had thoughts of suicide, imagining himself leaping to his death from one of the shining mountain-tops. He would gaze for hours into the blue-black sky at night, absorbed in the thought that soon his soul would be winging through that depth of space. One afternoon he actually scaled a cliff with the intention of dying there. Longing for death even while he rebelled against it, or believing that he longed for it, he did reckless things contrary to the doctor's orders. And he grew better and better on this perverse routine! He was convinced, as a result of this experience, that one does not die just because he has made up his mind to it. His improvement was so obvious that ultimately he too came to believe in it, and the realization struck him quite suddenly that he was going to live after all.

The courage of the other tubercular patients had helped him too, their unquenchable hope was contagious. Most of those who were able to walk about refused to acknowledge their disease at all, and even those who were bedridden were sure they would get well. (But then, they were not doctors!) One incident illustrating this

stubborn optimism remained in Cajal's memory long after He met here at San Juan de la Peña a young girl whom he had known when he was a soldier in Cataluña—once he had been billeted in her home He was shocked by the ravages the disease had made in her lovely face One day he asked her how she was

"Oh, fine! There's nothing the matter with me I have come here only to be with my father, who has a troublesome catarrh I am planning to get married in a few months " In a few months she was dead

Cajal grew tired of the monotonous routine of life at San Juan and decided that henceforth he would pay no attention to it or to his illness He put this determination into action at once, stopped drinking the waters, stopped taking his medicines, forgot all about diet and rest He lived a perfectly normal life, ignoring the protests of lungs and heart He threw himself into drawing, photography, hiking, and conversation, going at them as vigorously as if he knew he had a long lifetime to devote to them The beauty of the place, the serenity of the life, the rich milk and good meat, the long walks through the forest, the absorbing interests—all worked together He recovered, and his sister Paula, who had proved to be a perfect nurse and tender companion, had the joy of taking him home almost well again

Cajal himself attributed his cure largely to his enthusiasm for photography It had given him an outlet for the artistic impulses, always so strong in him, which had been smothered by his choice of anatomy and medicine as vocation Though photography was still comparatively new, it had long fascinated him, and now it led him to get exercise by taking walks with a special object in view—finding interesting scenes and wildlife to photograph It taxed all his inventive skill and his dexterity And the zest it added to days that might otherwise have been spent in boredom made the later weeks of his exile a period he was to look back on with actual pleasure in after years

FAILURE AND SUCCESS

ON HIS RETURN to Zaragoza, Cajal had gone back to his work in the dissecting room and to his researches. Since he was eager to depict the results of his discoveries in anatomy, he now set about learning how to make ultrarapid gelatin-bromide plates (These were very expensive, the process being hardly known in Spain, and he could not afford the prices charged by professionals.) He studied the directions in a book and quickly hit on the right way to go about it, even improving on the formula as he gained practice. To do this, he spent long evenings in an old barn pouring his sensitive solutions from one container to another, to the bewilderment of curious neighbors peering in through the window at his gaunt figure silhouetted against the red glow of a lantern, and probably suspecting him of being a modern Doctor Faustus trafficking in black magic and in league with the Devil.

In the following year, 1879, he prepared to take the competitive examinations for a position then open in Granada. Knowing the points in which he was weak, he made an effort to correct them. He steeped himself in the works of Ranvier, celebrated professor of the Collège de France. Learning to translate scientific German, he read the outstanding German works on anatomy. He found out all about the theories of evolution recently advanced by Darwin, Haeckel,⁵ and Huxley. He delved into embryology and even managed to acquire some of the elegance of expression that, in others, had so impressed the judges the year before. He was confident that he would succeed this time and was eager to show what he had accomplished. One day a friend, dashing icy water on this buoyancy, said to him bluntly

"Don't go up for the examinations. You're not ready yet."

⁵ Ernst Heinrich Haeckel (1834-1919) German naturalist. Author of the theory that an organism, in developing from the ovum, goes through the same changes as did the species in developing from the lower to the higher forms of animal life.

"But why?"

"Your time hasn't come yet. Wait until later and you will succeed well enough."

"But"

"Well, I'll tell you why. The professor who arranged the medical juries has taken it upon himself to see that Aramendia gets the professorship."

"But Aramendia's field is pathology, not anatomy."

"Just the same he'll be chosen. There is no chance of a vacancy in pathology for several years. His backers want him to get in somehow, and since the opening is in anatomy, they'll get him in through that door. Come, be reasonable. If you go up, you will only make enemies of the very people you will need to count on as your friends in the future."

"Thanks, but I have to go. My father will be furious if I don't."

On the day he went up for his "oral," Santiago found he had one implacable rival, a brilliant student, Don Federico Olóriz, later to become a professor in the Faculty of Medicine of the University of Madrid. Olóriz seemed to regard Cajal as his only real competitor, and when Santiago told him that Aramendia was the chosen one, he laughed scornfully.

"Why, he's only a bright boy, totally inexperienced in dissection!"

"Just you wait and see. This bright, inexperienced boy will be professor of anatomy at Granada and you'll be his assistant there or something equally dreary somewhere else."

"You're crazy!"

But Santiago's prediction—based on the one his friend had made to him—was to materialize directly. Olóriz won third place, Cajal was chosen second, Aramendia got the position in Granada. Cajal and Olóriz chafed at the injustice of it. Not that Aramendia was incompetent, he was a capable man, and had he wanted to, he could have become a notable professor of anatomy. But he had not yet had the preparation the other candidates showed so clearly,

and temperamentally he was more fitted to practice surgery than to teach anatomy. As soon as he could, he transferred from the chair of anatomy at Granada to that of pathology at Zaragoza, later rising to the chair of clinical pathology at San Carlos in Madrid. But Cajal had failed again.

A bit later in the same year, as the result of another set of competitive examinations, Cajal became Director of Anatomical Museums in the Faculty of Medicine of Zaragoza. His rival this time was an earnest young man from Valencia, for whom the judges from Cajal's university voted unanimously, while the three professors from other universities voted for Santiago. Honor in one's own country! The kindness and uprightness of these three judges, who did not yet even know him, determined the course of Cajal's career. If they had been influenced in their judgment by the cavilings of his colleagues, he might have had to become a practicing physician instead of a researcher, for his father, disappointed by his latest failure, was ready to wash his hands of him. And since, even now, Santiago was not entirely independent of his father financially, Don Justo might have had his way. Doubtless his son would still have tried to carry on his microscopic investigations as a hobby, but there is little time for hobbies in the life of a general practitioner with no money.

MARRIAGE

EMBOLDENED by getting this position and the modest security it offered, Santiago decided to marry. His father protested loudly, predicted all sorts of misfortunes. But this was a love match and his son was not to be held back. Cajal's account of his courtship in 1879 and his marriage the following year is revealing, though regrettably brief.

I became acquainted with my future wife in the following way. As I was returning from a walk through Torrero one afternoon, I met a

Explorer of the Human Brain

young woman of modest manner, accompanied by her mother Her rosy, smiling face was like that of Raphael's madonnas, or even more like a certain German print of Marguerite in *Faust*, which I had much admired I was attracted, no doubt, by the sweetness and gentleness of her features, the slender beauty of her figure, her great green eyes framed with long lashes, and the luxuriance of her fair hair But I was charmed most of all by her air of childlike innocence and the wistfulness which emanated from her whole person I followed the exquisite unknown to her home I learned that she had lost her father, a minor office-holder, and that she was a good, modest, industrious girl I became her suitor Some time later, the advice of my family being powerless to dissuade me, I married—not without studying thoroughly the psychology of my fiancée, which turned out to be, as I had hoped, the complement of my own

To my cronies in clubs and cafés my decision seemed sheer madness Looking at it from the financial standpoint, it is true it could have led to ruin Courage was certainly needed to set up a household when my entire income was twenty-five dollars a month, with eight or ten more, at most, gleaned from tutoring in anatomy and histology Because of this, the wedding was celebrated almost secretly, I did not wish to trouble relatives and friends with an affair that concerned my wife and me alone

I remember that a certain acquaintance, surprised at seeing me enter the ranks of the fathers of families with such confidence and intrepidity, cried out "Poor Ramón is lost for good! Goodbye to study, science, and lofty ambitions "

The predictions of friends and family were dire My father foretold my death presently, my friends gave me up as having failed for the last time

In principle, my censors were right. Certainly it is true that in most marriages feminine vanity and the needs and cares of the home exact the entire mental capacity of the husband to provide for them But one must take into account the special conditions, the temperaments of the individuals concerned, their tendencies, and their deepest feelings Besides, marriage often works a sort of alchemy, changing the physical and spiritual personalities of the married pair As a result of these changes and of the unity of purpose and activity the two now have in

common, a new entity emerges capable of creating completely new and unsuspected mental and economic values

Because they had not taken such factors into account, the prophecies of my friends and family were entirely wrong. Physically I improved so much that it was obvious to all that I had not been so well since my return from Cuba. My wife's devotion and tenderness spared no pains in establishing my health on a firm basis. As for my abandoning study and lofty ambition—a few years later, when I already had two children, I published my first scientific articles and won a professorship at Valencia.

Life had taken on new color for Cajal. His marriage in 1880 to Doña Silveria Fañanás García, despite the economic struggles that were to beset it for many years to come, was one of perfect harmony. It enriched his existence incalculably, as he testifies in his warm, deeply sincere appreciation of his wife.

It is an essential condition for peace and harmony in married life that the wife should accept willingly her husband's ideals and goals. The happiness of the home and the noblest ambitions are lost when the wife sets herself up as the spiritual director of the family and organizes according to her own ideas the activities and aspirations of her husband.

Far from diverting my slender income into the vanities of dress, the theater, or domestic luxury, my wife devoted her time and ingenuity to helping me pay for and continue my career. There was no money then for fine clothes, plays, carriages, or summer holidays, but there was enough for books, periodicals, and laboratory equipment.

In spite of a beauty which seemed to invite her to shine and display herself, she condemned herself joyfully to obscurity, remained simple in her tastes and without other ambition than peaceful pleasures, good management in the running of her home, and the happiness of her husband and children. That my choice had been a good one, considering my tendencies and my character, my parents quickly recognized, especially my mother, who became very fond of her daughter-in-law, with whom she had so many virtues in common and so many similarities in taste and outlook.

AN ERA OF PEACE

DURING ALL THESE YEARS since Cajal's return from Cuba, his turbulent country had been enjoying a period of comparative order and prosperity. Alfonso had been only a boy when he ascended the throne in 1875, but he soon showed promise of becoming a good king. He was moderate and merciful and did much to win back respect for the Spanish royal house, which the reign of his mother Isabel had done so much to bring into ill repute. His first task was to put an end to the Carlist war that broke out again upon his accession. The recognition of Alfonso by Pope Pius IX did much to strengthen his cause with the clergy and the people and weakened Don Carlos' chances of supplanting him. Early in 1876 General Primo de Rivera captured the headquarters of the Carlist troops, and Don Carlos, in March, fled across the frontier into France.

Spain was at peace at last. A constitution modeled on that of Great Britain was adopted, Spain thereby becoming a constitutional monarchy with a bicameral legislative body. But the people lacked the education in political affairs that a wiser government would have sponsored. They were not ready for such a constitution. The masses were illiterate, took no interest in social, economic, or political issues, and shortly became the unconscious tools and the victims of the local bosses. Under such conditions, a constitutional monarchy was bound to deteriorate into a dictatorship, although during Alfonso's reign the fiction of a true party system and free elections was kept up. But the people cared little. They wanted only peace and Spain had not been so peaceful since the death of Charles III a century before.

Salvador de Madariaga⁶ gives an interpretive picture of Alfonso

⁶ Salvador de Madariaga (born 1886) Spanish author, educator, and diplomat

and hence, in which, in the light of later events, is as apt as any variable to be

The result of that life was that he had known adversity, and therefore his country was less incomplete than had been the rule with Spanish rulers. He was a man who knew his mind and he seems to have had a true sense of the responsibilities of his position. He had a certain amount of information, but not a great one. Canovas con- sidered the country a far more important but he was not the man to quarrel with his fate. He was a man who had to live for a century. He relied on his own strength. He was a man who was not with the clear intention of governing a country, even though he had even though it, but never hon- estly with it. And although he was perfectly honest and honorable, even devoted to the cause of the country of political life which modern Spain did have.

He was effectively helped by his co-speaker, Sumner, in extended, convincing remarks who told the development of the Liberal party. Time and place were not very favorable, and he lived up to it. What in Chicago was a short speech, in New York, his countrymen, in Sigrist was a long speech. The Reformers rest their case on two symmetrical figures, the temperance and the ruling party.

And yet they found themselves ready to build up a normal and healthy political life, a life of free and independent mind. A Carlist curb on popular opinion, Canovas and Sagasta carried on a policy of make-believe. Instead of developing political habits in the people by enforcing a clean electoral law and respecting the opinion of the electorate (however restricted it might be), Canovas and Sagasta chose to invert in practice the system which had been outlined theoretically in the Constitution. The consequences of such a step were bound to be disastrous, and Spain fell full victim from them.*

Alfonso was popular with his people and so were his two wives. The first wife had been Mercedes, his cousin, second daughter of the Duke of Montpensier, husband of Isabel's younger sister, Luisa Fernanda. Alfonso's marriage with Mercedes was a love

* From *Spain* Quoted with the kind permission of the publishers Jonathan Cape Limited, London, and Creative Age Press, Inc., New York.

match, but it was an ill-starred one, for the wedding festivities were hardly over before Mercedes died of fever, leaving the king so bowed with grief that he never fully regained his interest in life, and his health, never robust, began to fail. The following year, for reasons of state he married María Cristina of Austria, by whom he had two daughters. Alfonso's reign brought stability to Spain and built up the prestige of the Bourbon house so firmly that it would be able to count on enough popular support to weather many severe crises in the decades to follow. His great sorrow was that he had no son to carry on his work.

Such was the state of affairs in Spain during the early years of Cajal's marriage, and the relative tranquillity of the period made it possible for him to pursue his work with peace of mind and with reasonable assurance that the longed-for opportunity to become a teacher in one of Spain's great universities would be granted him in due time and would not be blocked by social or political upheaval.

A PROFESSORSHIP AT LAST

IN 1883 the old bogey of the competitive examinations came up again, and again Cajal had plunged into the battle. This time there were two vacancies, one in the University of Madrid, the other in the University of Valencia. Always modest, Cajal competed only for the Valencia opening, while his former rival for the position in Granada, Olóriz, competed for both. In the intervening years there had been an exposure of the scandalous injustices often connected with appointments to positions, such as that done Cajal and Olóriz in their competition for the chair at Granada. To avoid a repetition of such blatant favoritism, the Minister of Education this time appointed a jury of examiners that was entirely beyond suspicion. Its president declared that only that candidate who was chosen unanimously would be appointed, and that this applied to both

positions. Oloriz won the chair at Madrid, Cajal that at Valencia, both by unanimous vote of the judges.

The chief of this incorruptible tribunal, substituting for the president, who had fallen ill, was the great scientist Letamendi, whom Cajal first came to know on this occasion, and who afterward was to become his revered friend and mentor. Later Cajal would make almost daily visits to his home and to the laboratory he had set up in his house for researches in microscopy and bacteriology. In later years Cajal was to help him make photomicrographs to illustrate his *Course in General Pathology* and to teach his assistant how to make ultraviolet gelatin bromide plates by which to reproduce them. Much to begeth the master was always to be stimulating to Cajal, Letamendi's wit and his brilliant intellect made working with him a kind of exhilaration.

Meanwhile, throughout all the active years in Valencia, now beginning, and later in Madrid, the gentle wisdom and loving self-sacrifice of Cajal's wife would be of inestimable help and comfort to him. So much was this apparent even in the early years of their marriage, and so freely did Cajal acknowledge it, that one of his friends used to say laughingly—yet meaning it too—"Half of Cajal is his wife."

6. *The Bewitchment of the Infinitely Small*

The experimental attitude . . . substitutes detailed analysis for wholesale assertions, specific inquiries for temperamental convictions, small facts for opinions whose size is in precise ratio to their vagueness

*With the advance of the experimental method, the question has ceased to be which one of two rival claimants has a right to the field. It has become a question of clearing up a confused subject matter by attacking it bit by bit. I do not know a case where the final result was anything like victory for one or another among the pre-experimental notions. All of them disappeared because they became increasingly irrelevant to the situation discovered, and with their detected irrelevance they became unmeaning and uninteresting.**

—JOHN DEWEY

BY the year 1884 when Cajal, now thirty-two years old, transferred to his new position at Valencia he had won the reputation of being a hard-working, earnest investigator. Upon moving to Valencia in January, he and his family took temporary lodgings in a hotel on the Market Square near the old Silk Exchange, one of

* The quotation above, from *The New Republic*, Feb. 3, 1917, is used with the kind permission of the publisher.

The Bewitchment of the Infinitely Small

the last remaining examples of Spanish medieval civic architecture. When they had succeeded in finding a suitable house and in buying the new furniture they needed for it, they went to live in a simple dwelling in the Calle de las Avellanas, where a few days later a second daughter, Paula, was born. Cajal was now the father of three children. The two eldest were a girl and a boy, Fé and Santiago.

Cajal was charmed with Valencia and spent a few days before becoming immersed in his work in exploring the romantic old city. He visited the ancient cathedral and climbed its tower, the Miguelete. He filled his eyes with the deep green blue of the Mediterranean. He made excursions to the picturesque suburbs and the enchanting little towns near by. He wandered about the seaport, the popular promenade, and the ruins of the Roman theater at Sagunto.

He soon made friends with his colleagues at the university and found them to be an excellent group of men. This is how one of them describes him in the early days in Valencia:

In 1884 a young professor who had just won by competitive examination the chair of anatomy at the university, appeared among us. It was Cajal. His somewhat neglected person had a dry, angular, rugged look about it. If this made him seem a bit uncouth, it was at once redeemed by his noble head. His forehead was broad and was made still broader by incipient baldness, by the slight depressions at his temples and his fine, straight nose. These gave him the stamp of intellect and distinction. His black eyes were remarkable too, their gaze dreamy when deep thought seemed to draw them back into his head, yet keen and penetrating when focused upon something in rapt attention. In spite of his blunt frankness and his temperament, which was more inclined toward seriousness than laughter, he quickly adapted himself to the gay atmosphere of the city and he soon gained the respect of both faculty and students by his learning. He won my friendship at once and shortly gave me his *

* *Boletín, Academia Española, Madrid, Oct. 21, 1934, pages 7-14*

In order not to become too one-sided in his almost fanatical absorption in microscopy, Cajal joined a social club, the Casino de la Agricultura, where he moved in a circle of agreeable and distinguished people. He became an ardent chess player, his only "vice." He joined a scientific and literary society, too, and there met some of the outstanding intellectuals of Spain. These were his sole extravagances, and he felt they were justified in that they saved him from the *gaucherie* and mental lopsidedness that characterize so many scientists who devote their time and energies to specialization in such restricted fields as he now contemplated for himself.

His home was modest, for to him a balanced budget was a strict necessity. Without it, he realized, neither domestic peace is possible, nor that tranquillity of spirit so indispensable to prolonged research without expectation of monetary returns. His house had a large room well suited to become his new laboratory, and it was soon full of activity. A busy laboratory, he found out, is about as expensive as a rapidly growing family—and he now had both, so he was well qualified to judge. To supplement his professional salary, he chose to do outside teaching rather than to resort to medical practice, which would leave him scant leisure for the research work now occupying the center of his thoughts. From the first he was very successful in his teaching, and he soon organized a course in normal and pathological histology, that branch of biology which deals with the origin, development, and minute structure of animal tissue and its appearance in health and disease. His lectures were attended by several physicians working for the doctorate and by others already in practice who wished to extend their knowledge, particularly in the new science of bacteriology, which was now rapidly winning a place for itself as a result of the brilliant work of Pasteur and Koch.

The additional income he earned in this way put his laboratory on a soundly functioning financial basis, and even enabled him to buy some new equipment that he badly needed, such as an auto-

The Bewitchment of the Infinitely Small

matic microtome, an instrument for cutting animal and vegetable tissue into thin slices for microscopic study (Its predecessor had been a common barber's razor, with which the boy Santiago had proved his skill in his apprentice days) Because he was miserably poor,¹ he used small animals, chiefly mice, for his experiments and would put a dozen different specimens on a slide His choice of the mouse, one of the smallest mammals, made it possible for him to follow through all the structures of the brain in a relatively small number of sections And because the nuclei of the cells were close together, he could see the nerve processes extending all the way to their destinations In this manner he was able to observe the whole architecture of this mammal's brain more completely than it had ever been done before

Though he was managing by extracurricular work and rigid economy to put his home laboratory on a fairly efficient basis, his facilities for teaching anatomy at the university remained meager He pleaded with the Minister of Education to make it financially possible for the university to get better equipment for its students, promising that if this were done, he would see to it that their original work in his department would win a place comparable with that held by the university laboratories of France and Germany "It is a disgrace," he said, "that among the many thousands of discoveries there is not one to which the name of a Spaniard is attached "

A little help was given, and Cajal kept his promise Within the next few years, a series of articles on various aspects of brain anatomy issuing from Valencia began to attract the attention of the medical world The new discoveries hinted at in these early publications were so different from the views generally held with reference to the intimate construction of the brain substance that they were largely discredited Perhaps remembering this experi-

¹ His salary—fifty-two duros a month—amounted annually to a little more than the equivalent of \$500

Explorer of the Human Brain

ence and many like it that he met with in later years, Cajal would write in his *Charlas de café* (*Conversations at the Café*) with a touch of bitterness "To be right before the right time is heresy, sometimes to be paid for with martyrdom" The more vigorous champions of the old concepts questioned the accuracy of his observations, the more open-minded were still to be convinced Yet in less than ten years Cajal's discoveries would become an essential part of all histological knowledge of the nervous system

THE CHOLERA EPIDEMIC OF 1885

CAJAL'S SCIENTIFIC PROGRESS was suddenly interrupted in 1885 by the cholera epidemic that raged that year in Valencia and later throughout all Spain Although Robert Koch had recently discovered the comma bacillus to be the cause of cholera, this knowledge had as yet been put to little use Microbiology was then only in its birth throes but it was already stirring up widespread interest and enthusiasm Many of the older histologists were deserting their earlier specialty to devote their energies to the virgin territory opened up by the study of pathogenic bacteria and the ways by which these microscopic organisms cause infection, illness, and death in men and animals Cajal, too, was momentarily attracted to it

For years afterward, the horror of the cholera epidemic remained in his memory The hospitals were bursting with victims, in Cajal's own street there were several cholera deaths, though fortunately his own family escaped unscathed There was bitter controversy among the doctors those loyal to the teachings of the old school held that the cause of the disease was the mist of the night air and administered laudanum, as advocated in the seventeenth century by the English physician Sydenham,² those of the new

² Thomas Sydenham (1624-89) Celebrated English physician, sometimes called "the English Hippocrates"

The Development of the Infinitely Small

school, and the younger men, recommended boiling the drinking water and eating no food that had not been thoroughly cooled. It was by following the simple precautions that Cajal's family preserved its immunity in spite of the fact that his laboratory was full of culture of cholera in solution and bath. When the epidemic was over he lost his fourth child, Jorge, who was born, on July 2, 1885.

At this time, when the eminent Dr. Ferrán came to Valencia, preaching the evangel of the cholera vaccine. After several experiments on animals and several in which he had heroically inoculated himself, he was convinced that he had found a culture of the disease which, when injected into a man, would immunize him against the possibility of its should enter his body through his mouth. The medical profession heatedly debated the subject of the new vaccine and finally was divided into two opposing camps of old and young of conservatives and progressives. The older men declared they could not see a great scientific error, if not an out and out medical failing in the remedy. But the devotees of Dr. Ferrán were not to be put aside. They organized a society for the purpose of spreading information about the use of the vaccine, of manufacturing it on a large scale and of obtaining from the Government permission to immunize all the people living in the districts in which the epidemic was raging. Cajal was urged to become a member of the society. But he was not absolutely sure of the efficacy of the vaccine and wished to remain open minded and free from any taint of mercenary motives, so he did not join it. Still, since he was a resident of Valencia and busy with work in microscopy, the provincial government of Zaragoza appointed him, together with Dr. Llate, the official delegate, to study both the disease itself and the proposed preventive measure and to prepare a statement on the subject.

Cajal threw himself into this task and in July, 1885, he traveled to Zaragoza to give his report. By this time the epidemic had

spread throughout almost the whole of Spain. He confirmed the theory, then still disputed, that the disease really was cholera and stated that in all probability it was due to the comma bacillus of Koch. But he was not inclined to put much faith in the anticholera vaccine prepared by Dr. Ferrán. He felt that its effectiveness had not yet been proved and that further study was needed before such a potentially dangerous culture should be widely administered in vaccine form.

By the end of September, Cajal had completed work on a large monograph prepared at the request of the provincial government of Zaragoza—*Studies on the Red Microbe of Cholera and Prophylactic Inoculation*. In spite of the fact that such a work would necessarily be chiefly a summary of information on the subject to date, with a careful evaluation and interpretation of the known facts, Cajal's report did contain some original conclusions based on his own experiments. One was a new, practical, and simple method for staining the comma bacillus so that it could be seen clearly when placed under the microscope. The most important contribution he made was his demonstration that hypodermic injection of a certain quantity of cholera culture that has been killed by heat stimulates the formation of antibodies, that is, stirs up the defensive mechanisms of the body to fight the virulent organism, and thus might possibly produce an immunity to the disease. This discovery—that vaccination of man and animals with *dead* cultures may produce immunity—has been almost universally attributed to two American bacteriologists, D. E. Salmon and Theobald Smith, who in 1886 published their treatise, *On a Method of Producing Immunity from Contagious Diseases*. The honor should go to Cajal, however, since he had demonstrated the same thing in this government report a year earlier.

Certain other points brought out in the report were of importance and were later confirmed by eminent bacteriologists. One of these was the doubt Cajal expressed (later corroborated by the

[108]

great Metchnikoff³ of the Pasteur Institute in Paris) that mere inoculation beneath a man's skin with a pure, live culture of bacilli cannot in itself immunize the digestive tube. This doubt was based on the fact that such a culture cannot migrate to the intestines and therefore cannot produce the symptoms of cholera, which is localized solely in the intestinal tract.

As was long to be the case with the work of Cajal, these original contributions passed unnoticed by the men of science of his day. Yet the effort he expended in preparing his elaborate monograph on cholera did not go entirely unrewarded. The provincial government of Zaragoza conferred upon him for his zeal a magnificent Zeiss microscope. His heart bounded with joy at this unlooked-for gift. Nothing could have pleased him better or been more directly useful to the career he was already carving out with firm, deliberate strokes.

His excursion into the study of the comma bacillus awoke in him a profound interest in bacteriology and pathology and he often wondered in later years if it would not have been more fruitful for him, both mentally and financially, if he had followed this path, which was then so fashionable. Histology condemned him to poverty, its greatest reward would be the grudging praise of the few scholars who could understand and appreciate his work. Bacteriology, on the other hand, was unworked soil, full of rich surprises, inexhaustible in discoveries leading to the relief of suffering and to popular acclaim and honor as one of the mercy-bearers of mankind.

But knowing his own nature, Cajal chose histology, the cautious way but also the tranquil way.

I knew well that I should never be able to drive through such a narrow path in a luxurious carriage, but I should be happy in contemplation.

³ Elie Metchnikoff (1845-1916) Russian zoologist in Paris. Discoverer of phagocytes and of phagocytosis. (A phagocyte [*phago*, I eat, *kytos*, cell] is any cell that ingests micro-organisms or other cells or substances, phagocytosis is the engulfing of other cells or substances by phagocytes.)

Explorer of the Human Brain

ing the captivating spectacle of minute life in my forgotten corner and listening, enraptured, from the eyepiece of the microscope, to the hum of the restless beehive which we all have within us

A more practical consideration influenced him too—the expensiveness of work in bacteriology as compared with the relative inexpensiveness of histology. He envisioned the vast hordes of experimental animals the investigator in pathology would have to buy, feed, and care for, the costly and varied laboratory equipment, the sterilizing ovens, the incubators! For histology one needs only a good microscope and a few standard reagents. So Cajal—now father of four children, earning fifty-two dollars a month—bade farewell, as he puts it, to the alluring microbe and remained faithful to his first love, the cell

THE REGENCY

SOME WEEKS after Cajal's return to Valencia in October of the terrible cholera year, the king, Alfonso XII, died after a brief illness—bronchitis—an illness so brief that it had hardly been announced before he was already dead. Serrano died the next day. The value of the peseta fell, and the royal household looked forward with dread to the revolution all felt was sure to follow. To avert this danger, Alfonso's minister, Cánovas, astutely turned over the government to the Liberal Sagasta, who by his appeasement policy staved off revolutionary outbursts. María Cristina of Hapsburg, wife of the dead king (his grandmother of the same name had died a year before Alfonso's second marriage), now became regent of Spain. According to the Constitution, her eldest daughter should have become queen, but María Cristina was pregnant, and in the hope that Alfonso's posthumous child would be a boy, she wanted no steps to be taken in this direction until after the birth of the new baby.

Early in May, 1886, a hurricane swept Madrid, causing great

distance to property and wide spread suffering. Maria Cristina, though the time for her confinement was drawing very near, spent her days roaming about the city, giving drive to the destitute and visiting the hospitals, she entered to the doors with victims of the disaster. On May 17 her child was born in life in the morning. A curious impression seemed to have been taken up outside the palace since dawn was going to reveal the birth. Everything hinged on the child's sex, for a boy would mean a crown. A high noon a cannon was fired the flag was run up, and Seso came out on a balcony to announce the arrival of a son. The crowd burst into wild cries and people were pressed for money of reward throughout the capital. Inside the palace Maria Cristina was weeping. 'Such a pity,' she said, 'if only she had died that my poor Alfonso might see the little son whom he wanted so much!'

Somehow this little child born alone drew together the warring factions of the people. And Queen Maria Cristina was strong enough and determined enough to hold him. Freedom for him, though she was only twenty-six when this difficult task was demanded of her. With the revolutionists adroitly handled by Seso, the only threat to her rule came from Don Carlos. His followers raised up a few sporadic uprisings, but the general respect for Alfonso remained and the sanction given it by the Pope weakened their hope of success. The Republicans were not much of a menace at any time during the Regency, for the memory of the anarchy that had accompanied their short time of power was still fresh in the minds of the people. Besides, the Republicans were divided into rival camps, which could have been united through the great capacities of Castelar, but he had no wish to effect such a union. Upon the birth of Alfonso XIII, then, Spain was more united than it had been for a century. It was a peace and union that lasted during the whole Regency, largely through the skill and intelligence of the queen, who had proved to be a remarkable woman. By the same methods her husband had used so effectively, she continued his work. Even Castelar gave his support to

Explorer of the Human Brain

her minister Sagasta Years later, when her son was to come to the throne, he would find it even more secure than it had been at the death of his father

CAJAL'S PUBLICATIONS OF THE PERIOD

UPON RETURNING to Valencia in the fall of 1885, Cajal had gone back to his study of living tissue, his enthusiasm for histology not at all tarnished by his recent detour into the more spectacular work with disease germs During the first three years of the Regency, as the result of months of uninterrupted toil, he published a series of articles on the structure of cartilage, on the crystalline lens of the eye, and on the muscle fibers of insects and of certain vertebrates But his chief concern at this time was the publication of an extensive work on histology and microscopic technique, *Manual de histología normal y técnica micrográfica*,⁴ the first installment of which had appeared in May, 1884 The next two years were devoted unstintingly to this monumental treatise, which when completed comprised 692 pages of small print and 303 woodcuts made from drawings of Cajal's anatomical preparations by an artist of Valencia This work was to prove a financial success (To his amazement, the first edition was sold out and a second edition had to be printed in 1893) Cajal's motives in undertaking it were fully realized He gathered together into one volume all his original observations in the field, minor discoveries that had gone practically unnoticed He disciplined his researches by making them fit into the rigid program demanded by a project of this sort And, most of all, he satisfied his patriotic wish to show foreign scientists that something original and worth while could come out of Spain, something personal, based on accurate, direct investigation and not a feeble reflection of the scientific productions of other lands

⁴ *Manual of Normal Histology and Micrographic Technique.*

The Penetration of the Infinitely Small

In the same year while writing his treatise, which shortly was to become world famous, he composed a series of popular-science articles for *L'Éclair*, a professionally weekly published in Zurich. The articles were fanciful, lyrical, with imaginative sweep they were foreign to the kind of his more serious work, to be excluded from them in his mind. They were signed "Doctor Pénetration," the pseudonym he always afterward to use for his writings in France for the layman. The emblematic served an important purpose: they showed how fascinating the study of cells and molecules can be and how rewarding, not only in personal terms, but in the contribution to be derived from this practically unknown field to the betterment and enrichment of everyday life. They bore their confidence and a robust faith in the certainty of scientific advance in the years to come. They showed at its full the author's passion to probe the mysteries of living things and his exhilaration each time his curiosity gained some slight advantage in its struggle with recalcitrant Nature.

The scientific literary writings reveal Cajal the man more and more than do his more technical works, in which Cajal the master scientist dominates the picture. Here is some of the magic the eye of the microscopist unveils, as he describes it:

the wandering white blood cell opening a breach in the blood-vessel wall and deserting the blood for the surrounding territory, like a prisoner who files through the grating of his cell, the region of the trachea and the larynx shaken with vibrating hairs, which wave, in response to hidden stimuli, like a field of grain before the wintry wind, the tireless toiling of the sperm cell as it hastens breathlessly toward the egg, the lodestone of its love, the nerve cell, the aristocrat among the structures of the body, with its giant arms stretched out, like the tentacles of an octopus, to the provinces on the frontiers of the outside world, to watch for the constant ambushes of the physical and chemical forces, the egg cell, with its simple, classic structure, guarding the secret of life, its form like that of a nebula whirling about in embryo innumerable worlds which will emerge in aeons to come,

the geometric architecture of the muscle fiber, a sort of complex Voltaic battery, where, as in a locomotive engine, heat is turned into mechanical energy, the gland cell, which in a simple way creates the ferments of our living chemical laboratory, generously consuming its own substance for the benefit of the whole, the fat cells, models of good housekeeping, which in preparation for future famines store up the surplus foodstuffs from the feast of life to utilize them when the organs fail and in the great nutritive conflicts of the body

Watch these protagonists of the struggle for survival fight it out on their own ground, he urges

Come with me to the laboratory There upon the stage of the microscope, tear up the petal of a flower, forgetting for a moment its beauty and its fragrance Then take a bit of animal tissue, tear it apart without compunction even though it pulsates and trembles at the touch of the needle Then look through the window of the eyepiece, and the leaf of the plant and the tissue of the animal will reveal to you in every part the same structure—a sort of honeycomb built up of little cells and more little cells, separated by connective substance, and harboring in its cavities, not the honey of the bee, but the honey of life in the form of a semisolid, granular material, encircling a tiny corpuscle, the nucleus

Now examine a drop of saliva, a few cells from the covering of your tongue, a drop of your blood, the mold found on decaying food—and always the same architecture appears cells and more cells, more or less modified, repeating themselves monotonously, with wearisome uniformity

This uniformity in the structure of organic tissues, liquid as well as solid, in the muscle as well as in the nerve, in the stem as in the flower, this precise repetition of the same melodic theme, forms the primordial truth of histology, the basic fact upon which is founded the grandiose and transcendental cellular theory of Schwann and Virchow

Anticipating the conclusions of later scientists as to the herculean warfare constantly being waged within the body, he continues

The Beautification of the Infinitely Small

Who will dare to deny that a strenuous rivalry exists in the race for the perfect cell, so that, in order to accomplish the supreme act of fertilization, they hasten toward the egg cell in a throng? Only one of the multitude must be the most fortunate, will survive the destruction that inevitably befalls the rest, to enjoy a happy companionship. It alone will receive the extension and multiply the ovum, then broadened and, long as it takes, it will unite with the female nucleus. From this life of love will at last a new cell, the cell of the new organism to be born. But only one pair of companion cells will sit in the reward of perpetuity. Therefore, and for a very long and stormy time, like a reserved virgin, the seed lies of life.

Concluded his description of such Homeric conflict. Capil pointed out some levels reached by philosophers and biologists who could not then know—that Nature is concerned, not with the life of the individual, but with the preservation of the species.

A whole life is sacrificed that may be even though ennobled by the fire of sacrifice, nothing in the eye of Nature. That a whole town should be destroyed, that entire race should be annihilated in the name of existence, that people formerly powerful should be sacrificed in the battle matter little to the controlling principle of the organic world. The essential thing is to win, to reach the goal that is the fulfillment of the cosmic evolution.

To soften the harshness of this picture, he tries to offer consolation for the inevitableness of Nature and of individual death by stressing the immortality of the germ plasm, the eternal substance of living nature. To most of us this is cold comfort, but it is the best he has to offer.

Let us console ourselves with the thought that if the cell and the individual succumb, the human species, and particularly the protoplasm, are imperishable. The accidental dies, but the essential, that is, the life, lives on. Comparing the organic world with a tree of which the trunk is the original protoplasm, the branches and leaves representing all the species later produced by differentiation and improvement, what

Explorer of the Human Brain

does it matter that some twigs are broken off by the storm if the trunk persists with unabated vigor, giving promise of shoots of even greater beauty and luxuriance?

But Cajal himself, commenting on this youthful thesis of his, remarks that it is a gloomy solace to die as a sacrifice to the survival of the species

Later there is a curious parallelism with the ideas of Schopenhauer and of Herbert Spencer, whom he had not yet read

This protoplasm filled both space and time with its creation, it crawled in the caterpillar, dressed itself with rainbow colors in the plant, adorned itself with the crown of intelligence in the mammal. It began unconscious and ended conscious. It was the slave and plaything of the cosmic forces and it ended as the driver of Nature and the autocrat of creation.

Whither is life going? Has it reached its limit and exhausted its fecundity in the human organism, or is it keeping in its portfolio plans for still higher organisms, for beings infinitely more intelligent and understanding, who are destined to rend the veil that covers first causes and to do away with all the laborious debates of science and philosophy?

Who knows? Perhaps this demigod, protoplasm, will also die on that sad apocalyptic day when the torch of the sun is quenched, when the embers in the heart of our globe grow cold and its crust is strewn with funereal ashes. Day of horror! Solitude filled with anguish, night of utter darkness, in which the light of the universe, the light of thought, is extinguished! But no. This is impossible. When our miserable planet is worn out and frigid old age has burned out the fire at its heart, and the earth becomes a glacial and barren desert, and the red and dying sun threatens to overwhelm us with everlasting darkness—organic protoplasm will have attained the culmination of its work. Then the King of Creation will abandon forever the humble cradle that rocked His infancy, will boldly attack other worlds, and will solemnly take possession of the universe.

"Forgive me," says Cajal in his mature years, "for these poetic effusions of my youth, which expressed what was then my credo—

and I had never read a word of Nietzsche!" These were to be his only ramblings in the misty domain of natural philosophy

"EXPORTING TO THE FOREIGN MARKET"

HAVING FINISHED his fundamental text on histology, Cajal was now eager to match his powers with those of foreign investigators. Only in contest with the strong does one gain strength, he told himself, and he longed to be admitted to the ranks of the leaders in science as urgently as when a schoolboy he had struggled to excel in physical prowess—with so many misadventures yet with eventual success. So it was to be again.

The first opportunity that presented itself was through Dr Krause,⁵ histologist of the University of Göttingen, who published a monthly magazine, *Monatschrift für Anatomie und Physiologie*, in which articles appeared not only in German but in French, English, and Italian as well. Dr. Krause had read some of Cajal's writings and asked him to contribute something to his review, promising to pay for the cost of the cuts and to give him fifty copies of the issue in which his article appeared. Cajal sent him two contributions, laboriously translated into French, with a large assortment of drawings he himself had made to illustrate them. The first article was sent directly, the second took him two years to prepare. It had to do with the texture of the muscular fibers of the feet and wings of insects, and became, as he developed it, an extensive monograph with four large color plates. Although it contained some original observations, its interpretations, based on the histological theories of the day, were quite erroneous, as Cajal himself was to demonstrate in his later work.

Having succeeded at last in "exporting his wares to the foreign market," he settled down to a study of the nervous system, the masterpiece of life. He studied it in various animals and in all its several

⁵ Wilhelm Krause (1830-1910) German anatomist

Explorer of the Human Brain

stages of development, guided by the outstanding works in neurology⁶ of the period, those of Meynert,⁷ Ranvier, Schwalbe,⁸ and others. The technical resources of the time, at least so far as they were known in Spain, were quite inadequate for such a study. With the staining methods then at hand, the best preparations showed hardly anything beyond the cell bodies and their nuclei, very little of the long nerve fibers conducting to and from the cell body could be seen. Therefore, even the most zealous investigation left the origin and the terminals of the fibers almost as much a mystery as they had ever been. Yet the structure of the nervous system, chiefly of the human brain, attracted Cajal irresistibly. Many basic questions regarding its function were still unsolved, crying for an answer. The new science of psychology, emerging dimly at this moment, was demanding exact information on the organization and processes of the brain, without which it could have no truly scientific basis. With it, it was then believed, the whole secret of thought and will would be laid bare.

CAJAL'S SOCIAL LIFE IN VALENCIA

CAJAL'S YEARS in Valencia, now soon to come to an end, were happy and full. Though most of his leisure was spent in his laboratory, he did allow himself some recreation with his fellow-members

⁶ Neurology is the study of the central nervous system and of the neurons of the peripheral nerves. It shares many fields in common with psychology and psychiatry, exact knowledge of the structure and function of the nervous system in health and disease is indispensable to a scientific approach to these two sciences. The close relationship of neurology to neurosurgery and neuropathology is obvious. Nervous anatomy, physiology, neurology, and experimental psychology differ from one another merely in emphasis and method. Fifty years ago neurology was just beginning to be recognized as a science. The main facts about it have been discovered quickly—first by anatomical methods, later by physiological.

⁷ Theodor Meynert (1833-92) Professor of neurology and psychiatry at Vienna.

⁸ Gustav Schwalbe (1844-1916) German anatomist.

To test hypnosis from all possible angles, experiments were also made on normal people, professional men chiefly. Cajal and his friends, after putting their subjects to sleep, were able to produce, by suggestion, hemorrhages, hallucinations, total or partial forgetfulness of the past and of the subject's own identity, multiple personality, and the remembering of things long since forgotten. The hypnotized persons would perform, after waking from the trance, actions suggested by the hypnotist that were entirely opposed to their normal activities and their natural bent. One patient adjusted his whole life for a week to conform to a ridiculous program outlined for him while he was hypnotized.

Cajal was quick to see the curative possibilities of hypnosis and straightway tried them out. He claims to have performed feats in this field quite comparable with those of the miracle-workers of the past. He was able instantaneously to turn the gloomy moods of depressed persons to joyous ones, to cause patients who had a phobia against eating to eat normally, to enable those hysterically paralyzed to walk again, to cause patients permanently to forget painful memories that were torturing them and making them ill, and even in one woman to produce by hypnotic suggestion complete insensitivity to the pains of childbirth.

Naturally his fame as a wonder-worker was spread abroad and his once peaceful home continued to be inundated with a throng of unbalanced people, some of them quite insane, begging him to cure them. (In the midst of all this, there was a new baby to care for, little Enriqueta, born in 1886.) Cajal helped as many of those who came to him as he could, without recompense, and then withdrew from the practice, his curiosity now satisfied. The only things that he was never able to fathom in this detour into hypnotism were the ability some of the subjects showed while in the hypnotic trance to see through opaque bodies, the transference of a sensation to the wrong sense organ, and mental telepathy. At spiritualistic séances, when this doubting Thomas visited them, the medium's skill seemed to melt into air thinner than her ecto-

7. *The Hard Bench of Analysis*

*A theory is not an unemotional thing. If music can be full of passion, merely by giving form to a single sense, how much more beauty and terror may not a vision be pregnant with which brings order and method into everything that we know? **

—GEORGE SANTAYANA

ABOUT the middle of the year 1887 a change in the medical curriculum of the Spanish universities left open several professorships in normal and pathological histology. These vacancies were to be filled, as usual, by competitive examination. Cajal competed successfully and two positions were offered him, one at the University of Zaragoza and the other at the University of Barcelona. It was hard for him to choose between them. Zaragoza attracted him, it was his alma mater, close to family and friends, and dear to him in its memories of his youth. But he chose Barcelona. Already he had come to realize that his life was to be dedicated to a consuming purpose and he feared the demands of living in the smaller city, knowing how easy it is to fritter away precious years in entertaining one's friends, or being entertained by them, and in combating the petty jealousies that thrive so luxuriantly in the overclose intimacy of a small university. "Holy peace" was essen-

* The quotation above, from *Reason in Science* (page 89), is used with the kind permission of Charles Scribner's Sons, New York, and Constable and Company, Ltd, London.

nal to the work he had in view. He needed, too, the laboratory and research facilities that Barcelona would offer so much more abundantly.

REMOVAL TO BARCELONA

THE CAJALS, therefore, moved to Barcelona and were soon installed in a modest house in the Calle de la Riera Alta near the headquarters of the Faculty of Medicine in the old Hospital of Santa Cruz. They did not stay there long, for Cajal soon found a way to supplement his small salary by giving private lessons in histology and bacteriology to certain young physicians in the city, and the family took a finer house, where Cajal set up a laboratory in a beautiful room opening upon a garden, in which he kept the animals he was to use in his experiments.

On the whole, he found the professors of the Faculty of Medicine a brilliant group of men, many of whom he later counted as true friends. They worked under difficulties in the dilapidated Hospital of Santa Cruz, where space for classes and laboratories was pathetically inadequate. Cajal was lucky enough to get a fairly large room in which to prepare his specimens and give his demonstrations, a room equipped with incubators and sterilizers and a good Zeiss microscope. He had only a few students, but they were hard working young men, and because of their zeal and their small number he managed to give them a more thorough course than that afforded by the far better equipped University of Madrid.

He was bent upon continuing the researches on the nervous system that he had begun while still at Valencia. But first he felt that he needed firmer grounding in pathological anatomy, in which he still considered himself a novice. He spent his leisure hours making autopsies and experiments. Every day as a result of these labors in the dissecting room he added to his collection of

Explorer of the Human Brain

tumors and to his assortment of specimens of infected or inflamed tissue. At last, after months of this, he was ready to return to his earlier investigations, with deeper insight now and greater technical skill.

A QUICK GLANCE AT THE NERVOUS SYSTEM

TO UNDERSTAND Cajal's work in the creative period now beginning, fundamental knowledge of the human nervous system, in both its structure and its function, is indispensable. For his life-work was largely an elaboration of details regarding this mechanism that so vitally controls our behavior and gives us our awareness of ourselves and of the world. Much of the modern concept, now to be summarized briefly, derives directly from Cajal's early discoveries and theories.

Structure At almost the very beginning of his career, Cajal was to prove that the basic unit of the nervous system is the nerve cell, or *neuron*. It is composed of three distinct parts: the *cell body*, which has as its chief function the nutrition of the neuron, and two easily distinguishable types of fibers extending out from the cell body: the *dendrites* and the *axon*. The dendrites are found in positions where they can be readily excited by stimuli (goads) coming from the outside environment or from neighboring cells within the body. They constitute the *receiving* end of the nerve cell, conducting waves of excitation, the nervous impulse, *toward* the cell body. Several dendrites usually branch out from the cell body in treelike fashion. The axon constitutes the *delivering* end of the neuron, it carries the nervous impulse *away* from the cell body and conducts it to muscle cells or to other neurons. Each nerve cell has only one axon, though this sometimes sends off branches, called *collaterals*, at right angles to itself. Both axons and collaterals terminate by branching into many tiny twigs (terminal arborizations).

The nervous system contains a vast number of neurons, which are the true nerve cells. It contains, too, a number of cells, called *neuroglia*, which take no part in the conduction of the nervous impulse, but serve to bind the system into a whole, their function being connective or supportive only. Some neurons are microscopic, but not all, for though all are microscopic in diameter, many are several feet long. Many axons, sometimes as many as 100,000, may be bound together with connective tissue to form a kind of cable, which is a nerve.

The cell body of the neuron is made up of cytoplasm¹ (that is, protoplasm exclusive of the nucleus) and a nucleus, which appears to play a dominant role in the life processes of the cell. In both the cell body and the fibers, the microscope reveals fine filaments streaming through the cytoplasm—these are the *neurofibrils*. They were once believed to be the basis of the neuron's power to conduct nervous impulses, but this now seems unlikely. Of greater importance is the *chromidial substance* (Nissl's granules) found in the cell body and in the dendrites for a short distance from it. Finally, there is the *Golgi apparatus*, a delicate network appearing in the cell body alone.

Some nerve fibers are naked but many are covered with a *myelin sheath*, a nonliving, fatty substance secreted by the neuron. This insulates and supports the *axis cylinder*—that is, the conducting core of the nerve process, encased within it. Myelin is white (because of the fat in it, just as the droplets of fat in milk make

¹ Protoplasm (*protos*, first, *plasma*, thing formed) is the form of matter of which all living things are made. It is a jelly-like substance, largely water, making up the essential material of all plant and animal cells and composed chiefly of proteins. Cytoplasm (*kutos*, cell, *plasma*, thing formed) is the stuff of which cells are made. The nucleus (*nux*, nut) and the cytoplasm represent internal specialization in cells. They differ from each other in structure and in chemical composition. Though they depend on each other, they have separate functions, the nucleus is concerned chiefly with heredity, growth, and reproduction, the cytoplasm with the more prosaic functions of absorption, secretion, excretion, etc.

it white), and fibers covered with it comprise the major part of the so-called white matter of the spinal cord and brain. Fibers that lack this covering are gray and make up the gray matter. Not much is known even today about the exact function of the myelin sheath. When individual fibers are important—as, for instance, in the neurons of the eye—they tend to be covered with myelin, while fibers that are a part of a diffusely conducting system, such as pain fibers and fibers going to the smooth muscles of the blood vessels and the intestines, are usually unmyelinated. Both myelinated and unmyelinated fibers may be encased in a thin, living membrane called the *neurilemma* or sheath of Schwann.

By using dyes to stain various parts of the nerve cells, neuro-anatomists have learned what is known today about the relations of neurons to one another. Dyes that stain the chromidial substance, for example, show where the cell bodies are. Dyes that stain the myelin sheaths or the nerve fibers themselves show the course the fibers follow and the interconnections they make. Detailed knowledge of the anatomy of the nervous system has been enormously advanced, therefore, by study of the neuron and of its inner composition, a study which Cajal carried far beyond the point at which he found it when he began his work.

Knowledge of neuronal structure sheds light upon whether or not the nerve cells are performing their functions properly. This is of great moment to physiological psychology because a very close relationship exists between nervous functioning and behavior. It is of great concern, too, to all branches of nervous pathology, the study of bodily ills in which the nervous system is involved. For instance, a physician or surgeon may need to know whether certain nerve cells are alive or not. He can find out in several ways. In neurons that are fatigued, the chromidial substance disappears from the dendrites, when the neuron is dying or already dead, it disappears from the cell body as well. Significant changes also occur in the Golgi apparatus upon the death of a neuron. Detection of these degenerative processes in the nerve cells has con-

siderable diagnostic value in medicine and is of great importance to neurosurgery

Function Neurons are grouped as *afferent* (carrying toward), *efferent* (carrying away), or *associational*, according to the function they perform in the nervous system. Afferent, or sensory, neurons are those that receive stimuli from the outside world, these neurons are located in the receptors, or sense organs, such as the eyes, the ears, the taste buds of the tongue. They carry the impulses set up in the receptors inward to the central connecting stations in spinal cord and brain. Efferent, or motor, neurons deliver the nervous impulse to the effector organs—muscles or glands—and thus bring about responses to the stimuli received by the sensory nerve cells. These reactions may be internal or external, voluntary or involuntary. The associational, or adjustor, neurons are the connectors, carrying the nervous impulse from sensory to motor cells. A large number of them may be involved in the simplest act.

The functional unit of the nervous system is the *reflex arc*, which is the smallest segment of nervous tissue that can carry out the special function of the system as a whole—the correlation of receptors and effectors. At least two neurons are required for this, and usually many more. If more than two are involved, all but the first (the afferent or sensory neuron) and the last (the efferent or motor neuron) are associational nerve cells. The reflex arc must therefore not be thought of as a group of neurons isolated from the rest of the nerve cells that make up the nervous system, it is in reality only a particularly easy pathway through it. In lower vertebrates, the nervous system is made up almost exclusively of reflex arcs, permitting only a very limited repertoire of responses. In the course of evolution, however, the animal nervous system has become more and more complex, with ever greater choice of nervous pathways and ever greater ease in forming new reflex arcs. In man the arc may consist of a vast web of interwoven paths, each containing many relays.

The nerve cells follow one another in a kind of chain, and, since they are distinct entities and separate from one another, tiny interruptions occur in the pathway of conduction. The junction between the axon of one neuron and the dendrites of the succeeding one is called the *synapse*. If an impulse is to be picked up by a neuron beyond the synapse, it must be strong enough to jump the little gap between the two nerve cells. Various degrees of resistance to the passage of the impulse are set up at this connecting point. Even today neurologists do not know with absolute certainty what the nature of this resistance is. But it is well known that when several impulses compete for right of way, the path of least resistance will be followed. Practice and habit strengthen some pathways, and others become so weak through lack of use that they virtually disappear.

One very important characteristic of the synapse is that it allows the impulse to travel in only one direction—from axon to dendrites. It is a one-way street. An impulse cannot jump the synapse backward, it must go forward toward its destination or drain away. This quality of irreversibility at the synapse is emphasized in the law of dynamic polarity, a law stemming from Cajal's theory of dynamic polarization, discussed later in this chapter.

Throughout the nervous system, pathways from different points run together into what is called the final common path, therefore, impulses from different stimuli can act upon one another. Impulses converging upon the same motor or adjustor neuron may combine to increase the degree of nervous excitation at the synapse. This is called *summation*. It is as if the neurons, the controlling elements of the body, consulted together before issuing their orders to the effectors, and having come to a joint decision, thereby increase the authoritativeness of their command. Summation is involved in most of the higher and many of the lower mental processes. For instance, one can combine the sensations of sight (redness) with those of touch (roundness, smoothness), of temperature (coldness), of consistency (moistness), and taste

(tinginess) to get a fairly complete impression of a frosty winter apple

But a complex nervous system cannot function harmoniously without another mechanism—*inhibition*, which is to summation as the obverse of a coin is to its face. For some muscles must perform actions reversing those of other muscles—for example, one must close one's hand before one can open it again. Therefore, voluntary muscles are found grouped in antagonistic sets, which must act alternately—while one set functions the other set is blocked or inhibited. In neurological terms, this means that under certain circumstances impulses arriving at a synapse not only fail to jump it but actually close it, for the time being to the passage of other impulses. Such blocking is necessary to prevent deadlocks and to facilitate alternative, useful action. Various theories have been advanced to explain the physiological basis of inhibition, none are fully endorsed today.

A mechanism fundamental to all learning is the *conditioned reflex*, which is a response, not to the stimulus that should naturally produce it, but to one that is connected with the original stimulus by association only. The famous experiment made by Pavlov² on dogs illustrates the operation of the conditioned reflex, or *conditioning*, as it is more popularly called. Food was presented to a dog and its salivary glands went into action. At the same moment a bell was rung. After this had happened many times, the dog 'learned' to salivate when the bell was rung even when no food was offered. The bell became a substitute stimulus for the real stimulus, food, which naturally elicited the response of salivation.

One could picture the human nervous system as it might be

² Some of the greatest recent advances in psychology were made by the Russian physiologist Ivan Petrovitch Pavlov (1849-1926), who would not admit that psychology was a science. His work on conditioned reflexes is one of the greatest contributions made to psychology and psychiatry within the last fifty years.

demonstrated in a transparent model of the body, with the nervous impulses visible as light.³ Because the impulses are minute and rapid, the brain of our imaginary model would shine in some parts with a steady glow and with shifting intensity in other parts. One would see flashes bursting out here and there, lighting up and fading to a glimmer. Little gleams of light would be observed traveling along the fibers, their brightness fluctuating at the synapses, and—when strong enough—kindling other nerve fibers beyond these connecting points.

Divisions The human nervous system is commonly thought of as comprising two main divisions: the *central nervous system*, which includes brain and spinal cord, and the *peripheral nervous system*,⁴ which includes all the ganglia (masses of tissue containing nerve cells) and the nerve fibers outside the spinal cord and brain. The central nervous system has several important parts: the spinal cord, the medulla, the cerebellum, the midbrain, the thalamus, and the cerebrum, with its outer “rind” or cortex. The function of the *spinal cord* is to convert impulses received from the sense organs, such as the eye and ear, into motor impulses, or muscular and glandular responses, leading, directly or indirectly, to action of some sort. It also serves to carry impulses to upper and

³ For this concept the author is indebted to Dr. H. Chandler Elliott's *Textbook of the Nervous System*, Lippincott, 1947.

⁴ The peripheral nervous system is so called because it is *away from* the central nervous system (which concerns us more nearly because Cajal's researches were made chiefly on spinal cord and brain). It comprises the *autonomic nervous system*, which regulates involuntary bodily responses, especially those involved in digestion, the circulation of the blood, and reproduction.

Claude Bernard said, when speaking of the functions of the autonomic nervous system: “Nature thought it prudent to remove these important phenomena from the caprice of an ignorant will.” Nature did not remove them entirely, however. Thought and emotion may react on the autonomic nervous system and on the closely related endocrine glands. Also the higher centers that control the autonomic nervous system are located in the brain itself. Followers of certain Oriental cults have sometimes achieved remarkable voluntary control over these supposedly purely automatic mechanisms.

lower levels of the nervous system. The *medulla*, about an inch in length, is a continuation of the spinal cord. Nervous impulses pass through it to the *cerebellum* above it and to the spinal cord below. It contains nerve centers that control circulation and respiration. The *cerebellum*, located at the base of the brain, is made up of two hemispheres and is connected by a structure called the *pons* (bridge) with the medulla and the midbrain. Its chief function is to maintain body equilibrium and muscular tonus. The *cerebrum*, the brain proper, includes the midbrain, the thalamus, and the cerebral cortex. The *midbrain* has to do principally with seeing and hearing. The *thalamus* is a large mass of nervous tissue in the center of the brain, through which most impulses from the sense organs pass before reaching the cortex. The thalamus seems to have something to do with one's feeling of pleasantness or unpleasantness, the general affective coloring of one's consciousness, whether cheerful or melancholy. The *cerebral cortex* is the outermost layer of the cerebrum, it is the seat of consciousness, of will, and of intellect. All these regions Cajal was to explore during his lifetime, first in lower animals of many species and finally in human beings in various stages of development.

EXPERIMENTS WITH THE SILVER STAIN

IN 1888, having completed his self-instruction in pathological anatomy, Cajal began to experiment one memorable day with a procedure for staining tissue known as the method of Golgi. Throughout the years before 1888, various methods had been tried for dyeing the nervous structures. None had proved adequate. However skillfully the methods in vogue were applied, the stains revealed little more than the cell bodies and their nuclei. The best procedures known were those of Ranvier and others who, following in his path, used silver nitrate and osmic acid, but the work called for unending patience and the results were far

from uniformly good. These methods were wholly inadequate when it came to tracing the beginnings and the endings of the nerve processes remote from the cell bodies and to disentangling the interconnections between cells. It was impossible, for example, to show by histological demonstration how a nervous impulse is transmitted from a sensory fiber to a motor fiber, yet this was a fundamental question, asked constantly by the budding science of psychology.

Accurate knowledge of the structure of the brain, in all its detail, was essential to a true understanding of its functioning in health and in disease. Brain anatomy, therefore, became a subject of widespread interest to medical men at this period, it was a field of investigation bound to prove irresistible to such a man as Cajal. "To know the brain," he once said, "is the same thing as knowing the material course of thought and will, the same thing as discovering the intimate history of life in its perpetual duel with eternal forces, a history summarized and literally engraved in the defensive nervous co-ordinations of the reflex, the instinct, and the association of ideas." But there was no compass to guide the explorer through the impenetrable forest of the gray matter. Still the outlook was not so dark as one might have thought at that moment, for the compass was soon to be devised, and by Cajal himself.

The method Cajal now set out to perfect was not his own invention but had been introduced in the years between 1880 and 1885 by the Italian anatomist and physician Camillo Golgi of Pavia (1844-1926). He had made great claims for it and through its use had made important contributions to the study of the brain. Later Golgi turned from this field as fruitless and became world-famous for his work on malaria, revolutionizing the medical treatment of this age-old disease. Other researchers did not have much luck with Golgi's stain and it became somewhat discredited. Essentially the method, designed to stain certain nerve cells, was first to harden the nervous tissue for a specified time in a mix-

tum of osmic acid solution and a solution of potassium dichromate. After several days the tissue was transferred to a silver nitrate solution for a day or two. Then the tissue sections were dehydrated in alcohol, cleared in oil of clove or oil of bergamot, and finally washed and mounted. This procedure was called the "silver stain" because of the use of silver nitrate when it succeeded the desired nerve cells stood out under the microscope etched in silvery black.

Cajal had learned of Golgi's chromic silver stain from the Valencian pathologist and neurologist Dr. Luis Sanmarro. In 1887 he had been appointed to act as judge for the examinations held in Madrid to promote his unedifying anatomy. While in the capital he took advantage of his opportunity to visit the leading scientists of his country to learn about the latest developments in histology and microscopic anatomy. Among other things he paid a visit one day to the central Biological Institute in the Calle de la Gorguera where several prominent physicians were doing research work. Among them Dr. Sanmarro, who had recently come back from Paris and was earnestly trying to arouse interest in scientific pursuits among the young men of Spain. Cajal spent unforgettable hours in the laboratory talking with Dr. Sanmarro about his studies of the degenerative changes that occur in the nervous system as the result of mental disease. It was at Sanmarro's house in the Calle del Arco de Santa Maria that Cajal first saw sections of the brain impregnated with Golgi's stain. He was amazed at the excellent results shown in these specimens and wondered why the scientific world had remained indifferent to a method that promised so much. Such negligence, he thought, could stem only from that childish egotism that makes the scientist feel disgraced if he uses a method invented by anyone other than himself, or from its counterpart on a larger scale, exaggerated national pride, which leads students to follow blindly the procedures taught them by their masters without ever experimenting with methods used by the leaders in other lands.

Explorer of the Human Brain

The two great passions of the man of science [says Cajal] are pride and patriotism. Scientists work, no doubt, from love of truth, but they work still more for their own personal prestige or for the intellectual supremacy of their country. A soldier of the mind, the investigator defends his native land with the microscope, the balance, the retort, or the telescope. As a result of this, far from accepting the progress made in other countries with interest and gratitude, he receives it grudgingly, as if it brought him insufferable humiliation, unless, of course, the invention is so great that to ignore it would be a sin against patriotism. How many times in my long career I have suffered from such pettiness! But I must hasten to say that there are exceptions, men who rejoice in foreign merit and take pleasure in helping it get its just due. But such noble souls are rare.

After his visit to Dr. Simarro, Cajal was impatient to get back to Valencia to try out the chrome-silver stain. No sooner was he at home again than he set to work making tests on the nervous systems of animals of various species, all of which strengthened his belief in the method he had stumbled upon so opportunely. But the procedure was undependable. No doubt, it was because of this capriciousness that Golgi, and later Simarro too, abandoned it. Enthusiastic though they both had been, they decided ultimately that the technique was suggestive rather than convincing.

Cajal's faith was not so easily shaken. He applied the silver stain, constantly perfecting it, to the various divisions of the nervous system, confirming the discoveries already made by Golgi. He made no new discoveries at first. Infinite patience was needed to adapt the method to the varying requirements of the structures to be studied. But Cajal was well endowed with an unending capacity for taking pains. Eventually he applied the procedure to the entire nervous system—with such success, indeed, as to win for himself the lifelong hostility of its inventor.

The year 1888 was a signal one for him. He called it his year of fortune. It brought the discoveries he had struggled for at the

cost of countless hours of toil and discouragement Without them he would have remained an obscure professor in a provincial university With them he became known throughout Europe and then throughout the world "From that time on," he said, "the trench of science had one more recognized digger "

REVELATIONS FROM THE EMBRYO

CAJAL'S IMPROVEMENTS in Golgi's chrome-silver stain made possible, to a large extent, the triumphs of 1888 But the vital thing upon which his early discoveries hinged was his idea that the method could be used with greater profit upon the brain tissue of embryos than upon the more complex brain tissue of adults When he put this premise to the test, using embryos of birds and small mammals, he found that the cells stood out complete in each microscopic section and the desired results were obtained more consistently than when adult tissue was used

The stage of development of the embryo had to be chosen carefully The tissue had to be stained and studied under the microscope at just the right moment, before the long processes of the nerve cells, the axons, had begun to be encased in their fatty coverings, the myelin sheaths, for these coverings obscured the basic structure The chrome-silver method, when applied to the embryo at this stage of its development, gave sharp coloration and the whole composition of the gray matter of the brain was revealed with startling clearness

How had it happened that scientists before Cajal had not studied the nervous system of the embryo? Golgi had once tried it but had abandoned it, somehow failing to realize what a rich field it offered But Cajal realized and plunged into it headlong Ideas boiled up in him and new facts burst forth so fast that he could not bear the slow tedium of publishing them through the regular channels, he had to have a publication of his own His

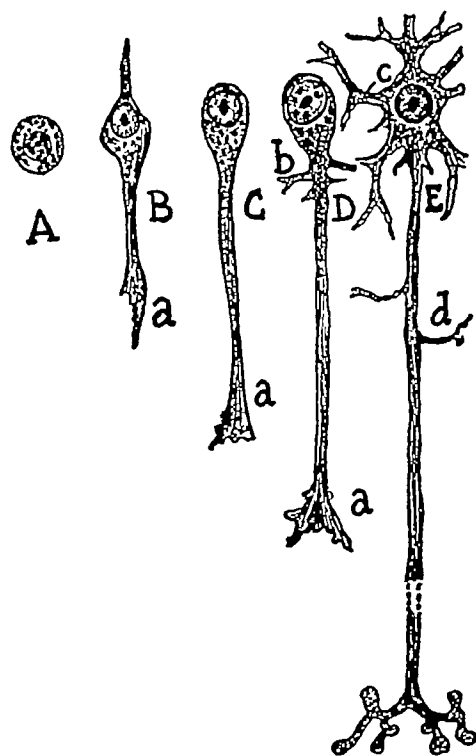


FIG 2 —DEVELOPMENT OF THE NERVE FIBER A, embryonic nerve cell, B, bipolar phase, showing the beginning of the growth cone, C, the neuroblast, D, dendrites appear, E, further development of the dendrites and formation of the collateral and of the terminal branchings of the axon (Courtesy of Dr E Horne Craigie, Professor of Comparative Anatomy and Neurology, University of Toronto, Canada)

magazine, *Revista trimestral de histología normal y patológica*,⁵ appeared in May, 1888, and again in August, with six articles by Cajal and six lithographic prints made by his own hands. The

⁵ *Trimonthly Review of Normal and Pathological Histology*

sixty copies, which were all he could afford to print, were distributed among foreign scientists

Even this timid venture into the whirlpool of publishing had swallowed up his small savings. And he had six children to support now—a new son, Luís, had been born during his first year in Barcelona. His wife, overworked though she was in taking care of them all, gave up her one servant to save expense. To match her sacrifice, in some small measure, and also to salvage every moment for his researches—now full of breathless excitement as he uncovered fact after fact—Cajal gave up his chess-playing with the cronies of the Casino Militar. He had already won a reputation as something of a champion. Before he made the final gesture of giving it up—and chess had grown on him almost like an addiction—he allowed himself the delicious joy of defeating his adversaries by ingenious tricks for a whole week. Then, his pride appeased and chess well out of his system, he bowed himself out of the Casino for twenty-five years.

Leaving temptation behind him, he threw himself into a study of the cerebellum of birds and of mammals. As a result of his researches in this field, he discovered the so-called basket cells and mossy fibers of the cerebellum, hitherto undifferentiated. He discovered, too, previously undetected branchings of the granule cells, the very small cells of the second layer of the cerebellum, and a sort of down appearing round the dendrites (peridendrite spines), later to be studied by many anatomists. In the following months he uncovered the delicate axon of the granule cell, with its long parallel fibers, and the climbing fibers that twine like ivy round certain cerebellar cells. These climbing fibers furnished the final evidence to substantiate the theory Cajal was now developing that nervous impulses are transmitted by *contact*.

The results of his studies of the cerebellum contradicted wholly the ideas then current as to the intimate structure of its gray matter. The opinions of the time were resolved into two hypotheses, and their advocates and opponents constituted two armed camps.

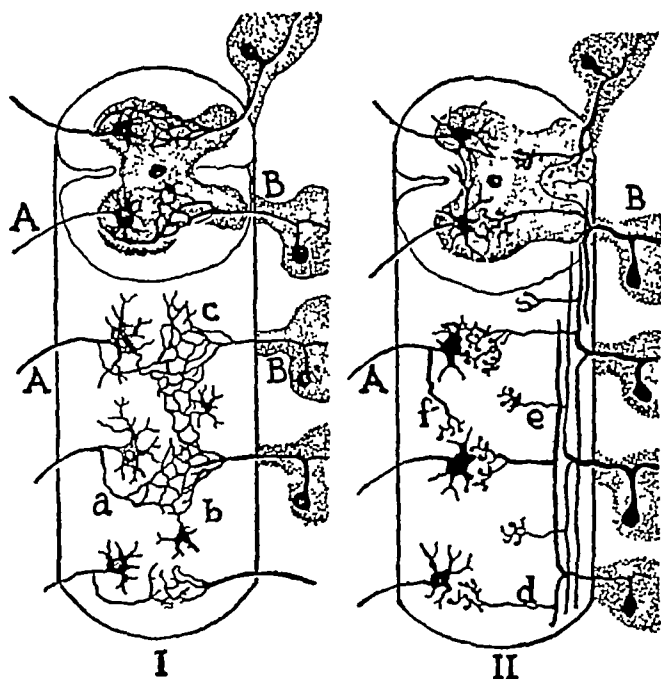


FIG 3 —DIAGRAM OF GOLGI'S CONCEPTION OF INTER-NEURAL CONNECTION (I) WITH CAJAL'S (II) A, anterior roots, B, posterior roots, a, collateral of the motor radicles, b, cells with short axons, which take part, according to Golgi, in the formation of the net, c, diffuse interstitial network, d, its broad collaterals in contact with motor cells, e, short collaterals (Courtesy of Dr Francisco Tello, Director, Instituto Cajal, Madrid)

Most of the neurologists of the period believed in the network theory, or reticular hypothesis, originally formulated by the German anatomist Joseph von Gerlach (1820-96). The other hypothesis, that of free endings, had been timidly advanced by two noted investigators, His⁶ and Forel,⁷ but had never been widely accepted. The network theory was given fresh and emphatic expres-

⁶ Wilhelm His (1831-1904) Eminent German anatomist and embryologist

⁷ Auguste Henri Forel (1848-1931) Swiss psychiatrist

sion by Golgi, who was its leading defender. This theory held that all the fibers of the nerve centers meet and fuse in the gray matter of the brain, forming a net, or reticulum, the Latin word for net. After explaining the reticular hypothesis in detail, Cajal describes the "network" as—

a sort of unfathomable physiologic sea, into which, on the one hand, the streams arriving from the sense organs were supposed to pour, and from which, on the other, the motor or centrifugal conductors were supposed to spring like rivers originating in mountain lakes. This was admirably convenient since it did away with all need for the analytical effort involved in determining in each case the course the nervous impulse follows through the gray matter. It has rightly been said that the reticular hypothesis, by pretending to explain everything, explains absolutely nothing, and what is more serious, it hinders, and almost makes superfluous, future inquiries on the structural organization of the brain centers. Yet the doctrine of reflexes, instinctive actions, functional localization in the cerebrum, and so on, imperatively demands the recognition of perfectly circumscribed channels of conduction through the cerebrospinal axis—cortex, cerebellum, spinal cord.

The opposing theory advanced by His and Forel was that the processes of the nerve cells end freely in the gray matter and are not intertwined in an elaborate network. But, if the nerves are not all interwoven in a sort of spiderweb, how are impulses transmitted from one to another? Forel thought that the processes of the nerve cells might touch like leaves on a tree. But both His and Forel merely offered hypotheses, they did not claim to have found objective evidence to substantiate their views. Golgi, however, reported careful investigation and observation as the basis for his sponsorship of the network theory. To refute him, one would have to prove that Golgi had actually observed, without realizing it, free nerve endings and also overlapping parts where the cell processes came into contact with one another.

This was precisely what Cajal set out to do, and he did succeed in furnishing objective proof of the theory advanced by His and

Explorer of the Human Brain

Forel With his discovery of the basket cells and the climbing fibers, he showed that definitely limited conduction paths exist in the gray matter, even though cells often do make connections with other nerve fibers coming from many sources. This conclusion, which he calls the *law of transmission* [of the nervous impulse] *by contact*, was substantiated by the investigations on the retina, the optic centers, and the spinal cord into which he now plunged.

It is difficult today, now that his findings have become a basic part of neurology, to realize fully how original and significant they were. Cajal's discoveries, hinted at in the modest papers he published in these years, were so much at variance with the current views on the essential construction of the brain that his observations were discredited by many investigators. It did not help any that these unorthodox views came from Spain—a country that had produced no great scientists for centuries, had never been outstanding in science at any time, and politically was a third-rate power, if even that. But in spite of his detractors and those who paid no attention at all to his discoveries, he had demonstrated beyond a doubt the fact that the principal element in brain tissue is not nerve *fibers*, as had been taught up to that time, but nerve *cells*.

It had long been known that nerve cells were connected with some nerve fibers, and it was known, also, that when these cells died, the fibers attached to them died too. To explain this, it was said that the cells in some mysterious way had something to do with the nutrition of the fibers, and when the cells died, the fibers died of starvation. The true state of affairs, as Cajal pointed out, is that the *cell* is the important part of the nervous system, the fibers being merely outgrowths of the cell. He showed each nerve cell to be a distinct entity, its prolongations touching but not continuous with those from other cells. This was a completely new idea, since up to this time, as was said earlier, the fibers were thought to be continuous with other fibers, forming a labyrinth of interconnection.

Also it was long supposed, before Cajal, that the nerve fibers ran down from the brain to the muscles and that those fibers along which sensation travels from the skin or sense organs to the brain were uninterrupted pathways. Cajal's researches showed, on the contrary, a series of nerve cells, following one another from the central nervous system out to the skin and muscles. At certain points, the branched ends of these nerve cells touched one another. But the nerve fibers attached to the cells, their prolongations or processes, were insulated from one another, except at the ends of the fibers. There insulation was lacking, and the nervous impulse traveled from one cell to another through these terminal contact points. The nerve cell, with its branches, was given the name "neuron" by Professor Waldeyer of Berlin and the neuron theory became the cornerstone of all later study of the intimate structure of the nervous system.

Cajal's concept that the nervous system is made up of individually distinct connecting nerve cells, the neuron doctrine, is frequently attributed to Waldeyer even today, many years after Cajal's death, and was often so attributed during Cajal's lifetime. Although Cajal was always more than willing to give full credit to the work of other investigators, he did resent the attribution of his doctrine to the German anatomist, whose researches had never even touched the subject. Cajal had devoted most of his life to confirming his early theory, Waldeyer had merely written a résumé of Cajal's ideas and had coined the word "neuron."

CAJAL EMERGES FROM THE LABORATORY

EMBOLDENED by his proved observations and fired with the wish to make his findings widely known, Cajal began to seek a way to get his views a hearing. He knew that pitfalls lay ahead. He would be blocked by those who had accepted as established the reticular hypothesis which he was about to overthrow. The fol-

Explorer of the Human Brain

lowers of Golgi, in particular, were bound to be combatants, even though Cajal was ready to give full credit to Golgi for his real contribution to minute anatomy before he had abandoned the field, and to acknowledge to the world that without the chrome-silver method introduced by Golgi his own discoveries might not have been made

He wondered why he had received no comment from the professors to whom he had sent copies of his *Revista*, published with such effort and at such a sacrifice in money, a commodity of which he had exceedingly little. He scanned the publications of 1889 for some recognition of his work, but it was either not taken into account at all or passed over contemptuously as of no importance. But Cajal was a fighter—had always been. He was determined that his observations should become known and justly valued. He planned his method of attack. Two courses were open and he adopted them both: first, to translate his most important papers into French (he realized that most European scientists outside Spain could not read Spanish) and to publish them in the leading German scientific periodicals, and second, to demonstrate his best preparations personally to the outstanding scientists in his field.

The translations were begun immediately and were energetically carried out. But it was the second course that was to prove more immediately fruitful—the direct, objective demonstrations. He became a member of the German Anatomical Society. For all his solitariness and his devotion to pure research, Cajal had enough practical sense to realize that it is the part of wisdom to exchange ideas with one's colleagues and to get to know those with whom one may have to contend. Through such relations bitter rivalry may be softened to mutual esteem and may even lead to cordial collaboration in tasks too vast for one man to cope with alone. So he broke his monastic rule of reducing social intercourse to the barest minimum.

The German Anatomical Society was holding a meeting at the University of Berlin early in October of that year (1889). This

was the golden opportunity. Full of hope with his scanty savings in his pocket and his beetle boxes and specimens in his bags, Carl started out for Germany. He stopped first at Frankfurt am Main, where he made the acquaintance of the German scientists Weirich⁸ and Ehrlich,⁹ the latter soon to become famous for his work on cancer and syphilis. He then went on to Berlin. On the eve of the opening of the Congress he found that a new epidemic disease had been awakened in his proposed cure for tuberculosis—a ray of hope that was soon to prove a mirage. The Congress would be remarkable for something quite different—it would mark the beginning of a new era in brain pathology and in the study of nervous and mental diseases.

Carl stirred up a fire of interest and curiosity at the Berlin meeting. It was unprecedented for the scientists to have known them a Spaniard who had devoted himself to scientific research. He waited patiently for a chance to give his demonstration—and when the hour came he was installed in a laboratory with a number of himing microscopes set up on tables in front of a broad window. He unspecked his precious specimens, requisitioned two or three of the microscopes—he had his own fine Zeiss with him—and focused them on his preparations while giving a lecture in bad French to explain what his specimens proved. Only a few histologists clustered about him, the others had gone off about their own

His listeners examined his preparations skeptically. But the specimens were clear and incontrovertible. The facts were there before their eyes. It was not long before the men who had come

⁸ Karl Weirich (1843-1904) German pathologist

⁹ Ludwig Edinger (1855-1918) German neurologist

¹⁰ Paul Ehrlich (1854-1915) German scientist of Frankfurt am Main. Renowned as the founder of modern chemotherapy. As a young man he was a color chemist and invented a method (Ehrlich's methylene blue) for staining living cells. He advanced the dye method of diagnosis of typhoid, standardized diphtheria antitoxin, and produced the first modern specific—salvarsan—effective in the treatment of syphilis.

to witness a fiasco were shaking the courageous Spaniard by the hand

"How did you get such preparations?" the observers demanded. "We have tried the method of Golgi again and again and got only failures"

Cajal tried to explain in his limping French the little secrets he had found out in handling the chrome-silver process, the practical rules by which it could be made less unreliable

Kolliker was enthusiastic. He took Cajal to dinner at his hotel and later introduced him to the chief histologists and embryologists at the Congress. "I have discovered you," he said, "and I want to make my discovery known in Germany." He wrote Cajal soon after his return to Barcelona. "You deserve a great deal of credit for having used the quick chrome-silver method on young animals and embryos. I shall not fail to make your admirable work widely known. I am glad that the first histologist Spain has produced is a man as distinguished as you, a man worthy of the nobility of science."

In 1890 and the following years a series of articles confirming Cajal's work would be published in the principal German scientific journals, especially in that of which Dr. Kolliker was editor, the *Zeitschrift für wissenschaftliche Zoologie*. It was unquestionably due to Kolliker and to his enormous prestige that Cajal's ideas got so swift and receptive a hearing. Yet only a little while before, Kolliker had been a firm believer in the network theory.¹ His intellect was flexible enough and his character big enough to enable him to abandon it and to proclaim the new concept—Cajal's theory of contact and of the neurons as separate, independent entities. He even learned Spanish in his old age and translated some of Cajal's articles himself. To Cajal, in his profound gratitude, Kolliker would always be the "glorious master."

It was at the Congress in Berlin that Cajal met Retzius,¹¹ pro-

¹¹ Magnus Gustav Retzius (1842-1919) Swedish histologist.

fessor of anatomy at Stockholm, the German embryologist His, Waldeyer, professor of anatomy and histology in the University of Berlin, and van Gehuchten,¹² then a young professor from the University of Louvain. On his way home, he stopped over at Göttingen and there met another distinguished scientist destined to be his friend all his life—Dr. Krause—who gave a dinner in his honor and showed him the sights of the town. Again, on the homeward journey, he stopped for a glimpse of the Alps and Lucerne and of Turin, Pavia, and Genoa. At Pavia he did not meet Camillo Golgi, who was in Rome performing his duties as a senator. Cajal was disappointed at this and felt in later years that if he had met Golgi at this time and had been able to express to him in person his warm appreciation of his work, much of the controversy that was to rage between them later could have been prevented.

His trip had been rich in results—far richer than his high hopes had anticipated. He had won recognition, made lifelong friends, broadened his outlook immeasurably. He was astonished at the educational conditions he saw in other lands. In Germany no standardized curriculum controlled by the state prevailed, with no competitive examinations for positions. Accustomed as he was to the centralized Spanish system, a close imitation of the French, he could hardly conceive of such a thing. And in Italy he found that famous men were earning salaries worse than those given for comparable work even in Spain. This too was a surprise. He came to the conclusion that the cultural superiority of the German, French, and Italian universities stemmed solely from the men who taught in them, not from the educational system or the resources afforded them, which were little better than in his own homeland.

¹² Arthur van Gehuchten (1861-1915) Professor of anatomy at Louvain

NEW STUDIES OF THE EMBRYONIC
DEVELOPMENT OF THE NERVOUS SYSTEM

CAJAL returned to his work in Barcelona with new ardor—more than ardor, a kind of frenzy. Now he had found his path. He worked every day from nine in the morning until midnight and it was rapture. Not only was his scientific bent finding satisfaction, his artistic drives were unleashed as well. The delicate configurations of the brain cells wove patterns of ineffable grace, at which his breath came sharply as he bent over the microscope. He made exquisite drawings of the new and ever varied designs etched by his silver stain. And the thrill of discovery! To him it was like finding uncharted islands or virgin forests that had been waiting from the beginning of time for someone to look upon their beauty. His excitement at finding out some new fact would keep him awake at night, or exhaustion would tumble him into a dreamless sleep from which he would awake with the solution of a hitherto unsolved problem clearly sketched before the eye of his mind.

This was the bright side of the picture. There was a darker side. For family troubles had come upon Cajal heavily in recent years. His eldest son, Santiago, was stricken with typhoid, which had left him with a heart ailment and mentally retarded. A daughter, three-year-old Enriqueta, became a victim of meningitis. After long vigils at her bedside, watching the little face grow thinner and more withdrawn, sick with worry and heartache, he would try to lose himself in his work. One night in 1889, when Enriqueta was dying, a new truth flashed upon his mind—his theory of the dynamic polarity of the neuron, a theory which he would put to the test in the years to follow.

The year 1890 was given over to the study of the development of the nervous system in the embryo—first of chicks, then of mammals. This was a subject that was tied in a knot of confusion. The

point that most needed clarifying was How are the nerves formed and by what means do the axons connect, without errors and wanderings, with the motor neurons of the muscles and glands or the neurons connected with the sense organs? There were two conflicting theories about this. According to the German neurologists Kupffer,¹³ His, and Kolliker, the primitive nerve cell in its early development gives off a kind of bud, which later becomes the axon. This, they believed, grew freely through the tissues of the body until it reached the terminal (the nerve of muscle, gland, or sense organ) with which it was supposed to connect. Others believed that the primitive nerve cell did not grow freely but that it went through a number of incomplete divisions. For instance, after the first division of the cell with its nucleus into two cells with their nuclei, one cell would migrate to the central nervous system (for example, to the spinal cord) while the other cell would stay at the surface of the body, constituting the first stage in the development of a sense organ. Finally, through more and more cell divisions, the long chain of the nerve fiber would be developed, bridging the distance between the first two cells. Cajal's investigations, throwing new light on this debated issue, definitely and conclusively supported the theory of Kupffer, His, and Kolliker, establishing as a fact the essential oneness of the nerve fibers and their dendrites. His observations of the chick embryo the second or third day after incubation showed clearly that the primitive nerve cell first sends out its axon and later produces the dendrites with their branchings. Axons and dendrites are attached to the cell body, growing longer and longer until their adult size is reached and finally connecting with their proper terminals. His had guessed this essentially, but with the cruder technique of his day was unable to see it actually happening. He therefore could not proclaim his theory as a certainty. But Cajal could and did see a nerve growing in the embryo of a three-day-old chick, the bud that was to

¹³ Wilhelm Kupffer (1829-1902) Anatomist of Munich

become the axon looking like a soft, flexible battering ram, ever pushing forward to its destination. Because it had a conelike shape, Cajal called it the growth cone. Today it is accepted as an established fact in the development of the nervous system. He was delighted with this discovery, for it enabled him to prove that his shrewd guesses of a few years before had been in the right direction.

The more he observed the elaborate, though sometimes seemingly groping, stages by which the development of the nerves unfolds, the more he was led to wonder what mysterious force prompts the budding and growth of the axon¹⁴ and impels it to beat its way implacably against every obstacle in its path. What causes the cells and fibers to travel in predetermined directions and finally to establish those connections which make the whole an almost miraculously efficient functioning unit? To answer this question he would later propound his neurotropic theory.

Cajal speaks of these fruitful years, 1890 and 1891, as his Palm Sunday. In them he had already, at almost the beginning of his researches, enormously enriched neurological knowledge and had proved the usefulness of Golgi's silver stain. Many learned men of the day, in Germany, France, Sweden, Switzerland, and even Italy in spite of Golgi's opposition, had already accepted his neuron theory and regarded as disproved for all time the long-established reticular hypothesis with its concept of a vast spiderweb of nervous interconnection.

No one was a warmer advocate of Cajal and of his contributions at this period than the young Belgian van Gehuchten, who later continued his work and became a scientific leader in his turn. It was largely due to his influence that Cajal's discoveries became

¹⁴ One end of the axon resembles an ameba in its form and movement. According to the modern view, it is at this end that growth occurs during the development of the nervous system in the embryo. It lengthens like the temporary protrusion the ameba puts out (the pseudopod) to serve for purposes of feeding and locomotion.

known in France, Belgium, and Switzerland. Professors Waldeyer and His spread Cajal's teachings throughout Germany. Retzius in Sweden eagerly accepted his doctrine that the nervous impulse is transmitted from one neuron to another by contact. Retzius' own experiments had proved to him that the axons never form a net but end freely and enter into contact at their terminals with the dendrites of other nerve cells. Soon these findings were to be reinforced by Lenhossék¹⁵ of Basle. In France, Dr. Léon Azoulay corroborated Cajal's discoveries in the cerebellum and spinal cord and became his official French translator. Professor Mathias Duval¹⁶ of the Faculty of Medicine of the University of Paris made huge wall charts of the drawings in Cajal's publications and would introduce his lecture on the nervous system with this gracious touch: "This time light comes to us from the south, from Spain, the country of the sun."

But all was not to be clear sailing. The field of scholarship and scientific investigation, like all other fields of human enterprise, has its petty competitiveness, its frenzied rivalries, its implacable grudges and hates. For Cajal this was to show itself in his long polemic with Camillo Golgi and his followers throughout Europe. In a sharp tone, at about this time, Golgi claimed to be the first to have discovered the adjustor neurons of the spinal cord (a discovery Cajal had made independently), calling attention to three lines of his in an unknown and unattainable Italian publication of 1880. Cajal acknowledged Golgi's priority in a polite note, in which he said he was sorry that such an important discovery should not have had wider publicity. Cajal's *amour propre* suffered something of a jolt from this encounter even though he had discovered many other fairly important structures about which there was no dispute.

¹⁵ Michael Lenhossék (1867-1937) Hungarian anatomist

¹⁶ Mathias Duval (1844-1915) French anatomist

THEORY OF DYNAMIC POLARIZATION

THE QUESTION that had presented itself with renewed force to Cajal as he bent over his preparations in the light of the microscope on the anguished night when little Enriqueta died was another enigma of the nervous centers. It was: What direction does the nervous impulse take within the neuron? Does it pass on to its destination in one direction, or does it spread out in all directions like the waves of sound or light? On this as on most neurological points at the time there was a difference of opinion, with nothing certain on which to base a solid conclusion.

Cajal's investigations of 1889 and 1890 on the retina, the olfactory bulb, and the cerebellum and spinal cord suggested that this problem—the direction in which the nervous impulse travels—could be approached from a new angle. In his studies of the visual membrane and the apparatus of the nose he had already observed that the thick processes of their cells closely resemble the dendrites of the nervous system as a whole. These thick processes, he noted, seem always to be directed toward the outside world and always conduct nervous impulses received from outside *toward* the cell body. On the other hand, the axons of these same cells were directed inward toward the central nervous centers. He believed the same to be true of the axons and dendrites of all nerve cells but had not sufficient proof yet to formulate a hypothesis.

Aided by his brother Pedro, who was making a study of the nervous system of the lower vertebrates, Cajal delved into the problem more deeply. He soon found abundant proof of his new theory, proof shortly to be accepted as valid by many neurologists, among them van Gehuchten, who had originally criticized it somewhat harshly. (Later he was to claim the idea as his own!) The new principle that Cajal laid down was this: The nervous impulse is always transmitted from the dendrites to the cell body, then to

the axon, which carries it toward the dendrites of a neighboring neuron. Every nerve cell, then, possesses a receiving apparatus, the dendrites and the cell body, and a transmitting apparatus, the axon, and finally a distributing apparatus, the terminal branchings of the nerve fiber. This unchanging direction in the course of the impulse implies a kind of permanent orientation, something like the attraction of the magnetic pole. So Cajal called the principle he had formulated the theory of dynamic polarization. Later he corrected the theory to make it more precise and to take into full account certain exceptions he encountered in his further researches, but essentially it remained the same.

Returning to his study of the retina and applying his newly discovered principle, Cajal now found in fishes and mammals two types of bipolar cells,¹⁷ hitherto undifferentiated, forming the channels from the rods and cones of the retina and leading toward the inner nervous centers. Two types of cells were demanded by reason, for the cones had long been known to be involved in color vision and the rods in night vision, in which color is absent. If impulses of both types were transmitted over the same channel, these two contradictory impressions would blend and mix and would not be sharply distinguished from each other, as we know them to be. But not before Cajal's work had it been shown by the microscope that two separate and distinct channels actually do exist in the retina of man and of certain of the animals. Having made this important contribution, Cajal plunged headlong into the study of the delicate structure of the cerebrum, the brain proper, the highest, most subtle, and most inaccessible of the nervous centers. As a reward for his hardihood, he clarified a number of important points about this dark maze.

By the end of 1891 he had assembled enough material from his original investigations to write a book. The chief ideas, with many of his charts and diagrams, were published in a series of articles in the *Revista de ciencias médicas de Cataluña* in 1892. They were

¹⁷ Cells having two processes

straightway translated into several languages, the German translation being made by Dr Held, one of the leading histologists of Europe. The French version, *Les nouvelles idées sur la fine anatomie des centres nerveux*, was made by Dr Azoulay, with an introduction by Dr Mathias Duval of Paris. It created a sensation and two editions were exhausted in three months. So Cajal decided he would gather together into one volume the results of all his researches on the structure of the nervous system of all the vertebrates. This formidable project exacted ten years of toil and resulted in the classic *El sistema nervioso del hombre y de los vertebrados* (*The Nervous System of Man and of the Other Vertebrates*).

His work now had to be interrupted by his need to study for the examination by which he hoped to win a position as a professor in the University of Madrid. The preparation for the tests and the necessary journeyings to the capital robbed him of the inner peace and the sustained concentration his researches demanded. He left them reluctantly, but his months of study were crowned with triumph, for he was unanimously elected Professor of Normal Histology and Pathological Anatomy at the College of San Carlos. His sixty published works did their share in gaining for him this hard-won success. The appointment was, as he had known it would be, of the greatest importance to his career, only in Madrid would he have the opportunity and the resources for the work that was to fill the years ahead—to say nothing of the means to recoup his finances, now badly drained by his experiments, his subscriptions to numerous foreign reviews, and the demands of his large family. "Only in the decorous industry of writing textbooks," he wrote, "as lucrative for the professors in the capital as it is precarious for those in the provinces, did I catch a glimpse of the financial security that would guarantee me, along with the precious mastery of my time, the supreme boon of independence of thought." Both these prime requisites to creative work were now to be furnished him in fair measure.

8. *The Ireful Stepmother*

Genius is the power of leaving one's own interests, and even to detach out of sight of entirely remote experiences or personalities for a time, so as to reconquer the living subject, clear vision of the world.

—SCHOPENHAUER

CAJAL'S return from the examinations in Madrid with the news that he had won for himself a transfer to the capital was met with mixed feeling on the part of his colleagues. They were proud of him—some few, perhaps, were a little jealous of his success. But for the most part they were sorry that they were soon to lose him and that they had neglected to make his position in Barcelona so attractive that he would not have sought new pastures. His special friend in the university, Professor Batlle y Beltran de Lis, was particularly disappointed at the turn affairs had taken, for he had planned to create for Cajal a position with suitable salary as microscopist for the Municipal Laboratory. These plans had been brought to nothing by the defeat of the Liberal party, of which Professor Batlle y Beltran was an energetic member, and the resultant change in the membership of the council that would have the final say in such an appointment.

Cajal had been at the University of Barcelona five years—the best work of his life had been done there—and he had made friends whom he hated to leave. They gave a banquet in his honor

Explorer of the Human Brain

at the Academy of Medical Sciences of Cataluña, a tribute that he recalled in later years with a glow of appreciation

On his way to Madrid to take up his new duties, he stopped at Zaragoza to visit his parents. It was a joy to him to see the pride and happiness his success had brought to his long-suffering father and mother. His former teachers at Zaragoza showered him with their good wishes and congratulations, and to make just return to them he consented to give two illustrated lectures on those of his discoveries that had already been corroborated by the foreign leaders in histology. He gave his lectures at the university, and in the traditional fashion his former colleagues at Zaragoza also gave a banquet in his honor, with toasts to his success and to the future of Spanish science.

REMOVAL TO MADRID

So, in April, 1892, forty years old now and the father of six children (another little girl, Pilar, had been born in the last year at Barcelona), Cajal finally reached Madrid, his portfolio bursting with the blueprints for new researches. He established himself and his family in a modest, almost humble dwelling that rented for sixteen duros a month. He realized that carrying out the plans with which his briefcase bulged would be a costly matter, and he had the education of his large family to think of too. Like his father before him, he had a horror of falling into debt and a contempt for the pretentiousness many provincial professors were guilty of when they finally "arrived" in the capital, setting themselves up in luxury, as he says, "like American dentists."

In view of the work he had in mind, he was pleased by the impersonality of the University of Madrid and the aloofness its professors could indulge in with impunity, knowing he would not have to dissipate his energies in fruitless social gatherings that so quickly eat up time and money to no purpose. "Blessed are those

who can say no," he would write later in his *Charlas de café*, "for they shall live in peace" Far different were the feelings of his friend and one-time rival, Dr Federico Olóriz, already transferred to Madrid, who was homesick for the warmth and gayety of Granada

But Cajal was glad Big cities, because of the distances one must travel to get anywhere, the many distractions, and the heightened tempo that insidiously robs one of his energies, are in themselves enough to cope with, he thought, and the scientist who wishes to accomplish something creative cannot fritter away time and strength on recreation "It is true," he said to himself when he first came to the capital, "no one gives me a thought, but in return what freedom I enjoy! What a privilege it is to be able to do my work when and as I want to without clashing with anyone!"

So Cajal started out with the firm intent not to let Madrid seduce him, but even he—disciplined and accustomed to solitude as he was—found it a harder battle than he had expected

Madrid [he says] is a city of danger The ease and pleasantness of social relations, the wealth of talent, the charm of the cafés and the *tertulias*, at which many men eminent in politics, literature, and science officiate as high priests, the theaters and a thousand other distractions captivate the man from the provinces, leaving him suddenly demagnetized and bewildered The bee is transformed into a butterfly, if not into a drone Philosophy, art, literature, even politics and pastimes tug at his soul with a thousand taut and invisible threads The busy worker has been replaced by the charming intellectual Sybante.

He did win out at last, by stuffing his ears to the siren song of the city and practically becoming a recluse, for which he had to pay the inevitable penalty of being thought queer, unsociable, and proud "Some relaxation is required," he presently told himself, "if the mind is to be refreshed and to broaden its horizons, but only when one needs it and not necessarily when others wish it Without some 'sanctified egotism' no one accomplishes any seri-

Explorer of the Human Brain

ous work " So to satisfy his needs and yet to salvage the precious hours, he allowed himself two recreations walks about the environs of Madrid and his club meetings at the café

The artist in him responded to the austere beauty of the landscape about the capital Far from mourning the loss of the verdure of the South, he loved the muted gray-blue, yellow-brown of this northern scene And the green was not entirely absent—the park El Retiro and the promenade El Prado he found to be among the most luxuriant and colorful spots of all Spain He loved the pure, crisp air, the rugged outlines of the mountains, the rhythm of the changing seasons

SOCIÁL LIFE IN MADRID

IN THE GATHERINGS of his club he discovered some of his army companions of the old days in Cuba The meetings in the Café de Levante sparkled with good fellowship, marred only by the grumblings of competent young doctors in revolt against the vicious system of promotion by seniority alone It was true that this system paralyzed all incentive to use one's full powers to carve a career for himself, since such a course was barred, while place was held for the idle and the unambitious But in no time at all, Cajal found, the young army men had petrified into living images of the older doctors whose lack of initiative they had once so vehemently resented Gradually Cajal withdrew from this club and joined the men at the Café Suizo, a group of professors, intellectuals, and political leaders The meetings took place in the early afternoon and lasted only an hour, so that they truly served the purpose of relaxation for which they were intended, without making too great inroads on time for creative work Through the meetings of the Suizo Cajal widened his knowledge of literature, art, and music (The musicians of the circle at this time were carrying on interminable debates for and against Wagner, the

[156]

politics of the age and the storm center of contemporary musical criticism.)

The members of the *Surro* were actively interested in political affairs without being in or out of any political group. They were politically normally independent, and on the warpath against any kind of dictatorship. They were indignant at the stupid policies of the day that had destroyed a fraction of the Liberal Constitution. The liberal men of the group belonged to the school that considered the past eternally to the past and looked forward to a future in which Spain's literary treasures would equal or surpass those of the Golden Age of Cervantes. The *Surro* delved into economic, social and educational problems, in which the condition of the poor could be ameliorated by a wise use of Spanish land and Spanish intelligence. In the not too distant future their optimism was to be shattered for a time by the catastrophe of World War I.)

Carballido was friendly in Madrid, most of them colleagues, like Oliva Calleja, Germán Ocampo, his mentor Letamendi (to whose home they all made daily visits) and other men of Spain who were already outstanding or soon to become so: most of them living, many immortally, like himself. Among them was the Marquis del Puerto, professor of obstetrics, who until his death turned over to Carballido's library of histology the salary he received as clinical director at San Carlos. Another was Dr. Calvino Martín, professor of surgery, who offered Cajal lifetime accommodations in one of his houses in recognition of the importance of the work he was doing—in offer which Cajal did not accept because he needed to live near the university and the house offered was remote from it in the Calle de Isabel II Católica.

THE NEUROTROPIC THEORY, STUDIES OF THE RETINA AND THE HIPPOCAMPUS

In 1892 Cajal propounded his neurotropic theory, a theory destined to prove vastly suggestive to later neurological research.

Explorer of the Human Brain

Some years before, while he was still at Barcelona, when studying the development of the nervous system in the embryo, he had tried to arrive at a reasonable explanation of why the budding axon beats its way so obstinately, despite all obstacles in its path, toward its seemingly predetermined destination. What force impels the growing nerve fibers to follow certain pathways to reach their proper terminals? Cajal came to believe that special chemical ferments are liberated round the cell bodies and the rudimentary fibers, ferments which condition the production of the outgrowths and their orientation toward their goal. He called these *neurotropic* substances (that is, substances having an "affinity" for nervous tissue) and thought them to be formed by the embryonic connective tissue, particularly by the cells of Schwann, which line the sheaths of the myelinated nerve fibers. These catalysts become active also after birth whenever a nerve is injured and tries to regenerate itself. Thus Cajal's researches on nervous regeneration in later years would corroborate these early findings with regard to the embryonic development of the nervous system.

In the years 1892 and 1893 he made elaborate researches on the retina of fishes and of birds, study of which had been begun in Barcelona, particularly the region of the retina most sensitive to color. A professional animal-catcher kept him supplied with snakes, lizards, owls, crows, salamanders, perch, and trout, and a friend in Cadiz sent him specimens of the chameleon that lives in the sand dunes of the Spanish seacoast. His notebooks were soon filled with sketches. He used this material in one of his most important publications, a volume of observations first published in the Belgian review *La cellule* and later translated into German.

In addition to these detailed investigations on the retina, he made a study of the hippocampus, the ridgelike structure in the temporal lobe of the brain. (Its name is derived from the Greek word for sea horse because the hippocampus has something of the shape of a sea horse, with its large head and long, curved tail.) Though largely vestigial in man, the hippocampus is a part of the

[158]

rhinencephalon or "smell brain,"¹ which, in addition to containing the brain center for the perception of odors, stores away memories of familiar smell and the characteristic reaction the organism make to them. The smell brain is very important to lower animals for their self preservation, and it is the oldest association area of the human brain. For higher in primitive man and more vital to him than to human beings today. Cajal confesses that one of his reasons for choosing the study of the hippocampus was his artist's love of the beauty inherent in the architecture of its cells and their fibers which he saw as he had out like newly planted hedges of hawthorn.

The hippocampus had been investigated by Golgi, and it was in his book that Cajal first saw pictures of its formal elegance. But there was still a champion out for further research. Golgi and his devoted followers had not gone into a thorough examination of the cell with their microscope of the connections between the neurites of the hippocampus to determine the exact pathways followed by the electricory impulse upon reaching this portion of the brain. Cajal now set himself the task of unravelling this enigma. The result of his work was a huge monograph published in 1892 in the *Archives de la Société d'Étude de l'Anatomie et d'Histologie Naturelle*. This was translated into German the same year by his friend Kolliker and republished in the review of which Kolliker was editor. The year 1892 saw various other publications, bringing out other new, though less important, details about the nervous structures of man and of the lower animals.

¹ The primitive brain of lower vertebrates has a larger proportion of its mass devoted to smell than do higher organisms. The smell brain is the oldest part of the cortex. Smell has an intimate connection with the expression of emotions. Kipling was quite accurate when he said, "Smells are surer than sights or sounds to make the heartstrings crack."

JOURNEY TO ENGLAND

IN 1894 Cajal received a signal honor—he was invited to give the Croonian Lecture before the Royal Society of London.² His fame was indeed spreading and far beyond the confines of his native land. The discourse called the Croonian Lecture had been instituted by an English scientist for the purpose of bringing to London as speaker a scientific investigator who had made some significant discovery, and the honorarium was £50 (then about \$250).³ Its purpose was primarily to stimulate original research on the part of England's own men of science, it was also a means by which they could get to know foreign discoverers, hear them explain their own work, and evaluate it for themselves at first hand.

Cajal was astonished at this invitation. He had not done anything of such great note, he thought, that he should be singled out among all the illustrious men of Europe. His natural shyness and humility made him hesitate to accept, and he toyed with the idea of courteously declining the honor for fear that he would not measure up to expectations. He was keenly aware that the Royal Society of London is the greatest scientific institution in the world. To become one of its Fellows, to be able to place the vaunted F.R.S. after one's name, is granted to very few. Kolliker had given the Croonian Lecture in 1862, and the Scandinavian investigator

² The Royal Society of London is the oldest scientific society in Great Britain and one of the oldest in Europe, having been established about 1660. It gives advice on scientific matters and administers grants for scientific research. To be admitted every candidate must be sponsored by six or more Fellows. The best papers read before the Society are published in its *Proceedings* or in its *Philosophical Transactions*.

³ Dr. William Croone, Fellow of the Royal College of Physicians (London), left behind him at the time of his death in 1684 a plan to found a lectureship but with no endowment for the purpose. Many years later his widow provided the funds needed to carry out the plan. The first Croonian lecture was given in 1749 by Thomas Lawrence.

Reizius had once given it. Capri's immediate predecessor had been Virchow, father of modern pathology. To make him hesitate still more, one of his daughters took sick at just that moment and he was reluctant to leave home.

On the other hand powerful influences were moving him to go. His family doctor assured him that his daughter would get better and would be well looked after in his absence, his wife begged him to accept the honor done him, and he received a warm invitation from Dr. Michael Foster⁴ of the Royal Society and an equally heartening one from Professor Charles S. Sherrington,⁵ a leading neurologist even then, though a young man, and today the outstanding physiologist of England. Professor Sherrington invited him to stay at his house.

Capri could not speak English, so he prepared his lecture in French, Spanish being too little known in England to admit of his giving his address in his native tongue. He gathered together his very best preparations of the cerebellum, the retina, the spinal cord, the olfactory bulb, and several others, and set out for London. On the way he stopped in Paris to visit his friend Professor Mathias Duval and his French translator, Dr. Azoulay, who corrected the French of his discourse, which was entitled *La fine structure des centres nerveux*.⁶

He was welcomed to London by Professors Sherrington and

⁴ Michael Foster (1837-1907) English physiologist. Professor at Cambridge. He played a large part in the organization and development of the Cambridge biological school. His *Textbook of Physiology* (1870) became a standard work in the field.

⁵ Professor Charles Scott Sherrington (born 1861) would himself give the Croonian Lecture three years later, in 1897. In 1932 he and Professor Adrian of Cambridge would divide between them the Nobel Prize for medical research. Dr. Sherrington held professorships at Cambridge and later at Oxford, retiring in 1935. He formulated the general principles of reflex action and is referred to by Professor Asher as "the philosopher of the nervous system."

⁶ Printed in full in the *Proceedings of the Royal Society*, Vol. 55, 1894, and abstracted in the *British Medical Journal* at the same time.

Foster and was touched by the warmth of their hospitality. On this visit he also met the distinguished British mathematician and physicist, Lord Kelvin. He was impressed by Lord Kelvin's cordiality and by the friendliness and the unassuming simplicity he encountered in all these men, the greatest scientists of their time.

An amusing anecdote is told of Cajal while he was staying at Professor Sherrington's. Whenever he was about to leave the house to go out, he would lock his bedroom door and take the key with him. His hostess did not quite know what to make of this. An old Spanish custom, perhaps? But the maid did have to get in to put the room to rights. When at last they found another key and unlocked the door, they saw at their first glance that the room had been transformed into a little laboratory. Bottles on the window sills, on the chairs, on the floor! In the seclusion of his bedchamber Cajal was carrying on a few experiments, no doubt impatient to find the answer to some problem that had been plaguing him before his work had been interrupted by this unexpected trip to England.

Every discoverer invited to give the Croonian Lecture was awarded an honorary doctor's degree by Oxford or Cambridge, the choice of university depending on the guest's field of endeavor. In Cajal's case it was to be Cambridge. When leaving London for Cambridge, to make sure he would be at the station in time, Cajal reached it too early and boarded a train that left sooner than the one he was supposed to take. No one met him at the station at Cambridge but, in his modesty thinking nothing of that, he went directly to the university and spent delightful hours visiting the colleges and reveling in their beauty. He did not know that a luncheon had been prepared in his honor, and that his would-be host had been in consternation from the moment he had failed to appear at the station when the right train pulled in. Long after the luncheon was over, his friends found him and set him up in lodgings in one of the buildings of King's College.

The degree of doctor of science was conferred upon Cajal on

March 5, 1807. His hosts escorted him to the solemn ceremony held in the magnificent convention hall of the Senate House. He was decked out in the traditional cap and gown, which he describes very scientifically, as "a kind of red toga with a special cap the top of which is finished with a pyramidal attachment having a square base." He was nervous and ill at ease in this quaint attire as he marched down the aisle to the music of Beethoven. A long discourse in medieval Latin followed, in which the speaker amusingly pointed out that Cajal's fellow countryman, the Roman poet Martial (born in Spain about A.D. 41), would have had much in common with his modern brother and would have appreciated his work. For Martial too had learned from experience that little can be accomplished in the world without silver. This was, of course, an allusion to Cajal's use of the silver stain—since in all other respects silver figured very little in his life. (Even at this period of his career his yearly salary in Madrid, in a position involving an enormous amount of routine work, was not more than \$800.)

At the end of the ceremony Cajal had to sign his name on the long roll of honor—with a quill pen so as not to break the tradition. Then there was a banquet at King's College and another dinner, in the days to follow, at Dr. Michael Foster's fine house in the country.

While at Cambridge Cajal attended a scientific gathering at which each investigator demonstrated his discoveries—the histologists their microscopic sections, the physicists their new inventions, the chemists samples of newly discovered substances, the bacteriologists specimens of new germs. All this was naturally of immense interest to him, and, he foresaw, of tremendous educational stimulus to the students in residence at the university, for in this way they gained direct contact with the greatest scientists in Europe and an intimate view of their special accomplishments.

Though Cambridge had done him such honor, it was to Oxford that he lost his heart.

Of my visit to Oxford, that beautiful city, precious jewel of the Middle Ages, where every house is a historic shrine and each college rivals a royal palace in richness and magnificence, I can only say that I was overwhelmed by it. The museums! the Gothic chapels! the comfort of the students' quarters! The finest of our educational buildings at home seemed no more than a jumble of stones and lumber in comparison with the exquisite architecture of Corpus Christi and Magdalen, and with John's College, half hidden in its mantle of ivy.

One of the experiences afforded him while he was at Oxford, perhaps the one he enjoyed most keenly, was a visit to the laboratory of Dr. Langley,⁷ known later for his discoveries with reference to the sympathetic nervous system.

Upon Cajal's return to London, Professor Sherrington aided him in the further preparation of his lecture and had photomicrographs made of his finest specimens so that they could be projected on a screen. He also provided his guest with what he needed to make large colored wall charts to illustrate his talk. With these visual aids to help him, Cajal's lecture was a success in spite of his nervousness. It was given on March 8, 1894, at Burlington House, with Sir John Lubbock as chairman of the session. After summarizing the newer histological methods that had come into use, particularly those that had proved fruitful in his own hands, Cajal described the minute anatomy of the cerebral nerve cells, tracing some of the nervous pathways within the brain, especially those that have to do with the olfactory and visual systems. He demonstrated the direction of the nervous impulse within the nerve cell from dendrites to cell body and from cell body to axon. In so doing, he explained his theory of the dynamic polarity of the neuron, a theory which has since become an established part of physiological psychology.

Two courtesies extended to Cajal at this great moment of his life remained ever afterward in his memory: the directors of the

⁷ John Newport Langley (1852-1925) Professor of physiology at Cambridge University.

meeting had had summaries of his chief points printed and each listener had a copy to glance at as the speech progressed, and above the speaker's platform the flags of Great Britain and Spain hung side by side.

The Spanish ambassador and other Spanish representatives at the embassy were present at the lecture and congratulated him warmly when his speech was done. Cajal was overwhelmed by a series of formal dinners in his honor, the most important being the banquet given by the Royal Society, at which hearty toasts were drunk to Spanish and British science and to the lasting bond of friendship between them. Dr. Foster peppered his after dinner speech with witty courtesies to the effect that, thanks to Cajal's researches, the impenetrable forest of the nervous system had been converted into a well laid out park, and that his studies had built up connecting collaterals and motor end plates between the soul of Spain and the soul of England, formerly kept apart by centuries of misunderstanding and indifference.

At another dinner, this one held at the Spanish embassy, the ambassador, Don Cipriano de Maza, lavished such praise on his countryman that Cajal was almost too embarrassed to thank him. "In all my travels about the world," Don Cipriano said, "there have been three occasions when I have been deeply impressed on viewing Niagara, on visiting the Coliseum at Rome, and on listening to Cajal's speech before the Royal Society."

When all the celebrating was over and Cajal could settle down to some real peace and enjoyment, he visited London's points of interest—the British Museum, the Crystal Palace, and Westminster Abbey, where he bowed his head in reverence before the tombs of Newton and of Darwin. He visited the schools, laboratories, and hospitals of London as well. He was deeply interested in the experiments on animals being performed at this time by the English physiologists, in which portions of the nervous system were removed by delicate surgical procedures. The experimenter then made a careful study of the reactions of the animal after it

was thus deprived of essential structures. By this means it was possible to arrive at more accurate knowledge of the specific function of these structures and of their relationship to the nervous organization as a whole. If the animal was to survive such extensive operations on mechanisms of vital importance to its life and its normal activity, the surgery had to be done with consummate skill. One such experiment performed by Professor Ferrier⁸ on a macaque made an unforgettable impression on Cajal. Both occipital lobes of the brain were removed and with such dexterity, such absolute cleanliness, and such control of blood loss, that the animal lived through it, and, as a result, the investigator could explore the nervous degeneration that took place in its functioning progressively as other structures withered away. Ferrier was to become one of the chief scientists associated with the localization of the sensory and motor areas of the human brain.

While on this visit Cajal was enthusiastic at what he saw of the English educational system, but his ultimate judgment was that it was directed rather toward developing men than developing scholars. Though England has produced many great scientists, he felt that they owed little to the universities, they were, rather, "privileged minds" who blazed their own trails without being deeply influenced by the formal curriculum from which they had emerged. In this sense, he found the English investigators to be far less the product of their schools than the scientific geniuses of Germany were of theirs. More scope was offered by the English system for individuality, while the German system, with its rigid discipline, instructed more and educated less. Perhaps, he mused to himself, the perfect educational system would be a balance between the two.

⁸ Sir David Ferrier (1843-1928) British neurologist. Professor of medicine and neuropathology at King's College. Did outstanding research on the physiology of the brain, particularly with reference to the localization of cerebral functions and on the removal of brain tumors. His *Croonian Lecture on Cerebral Localization* appeared in 1890, his *Regional Diagnosis of Cerebral Disease* in 1910.

BACK HOME AND AT WORK AGAIN

THE UNIVERSITY OF MADRID seemed a dreary place after Cajal's return from England. He shuddered at the sight of the ramshackle buildings in bad repair, the unhygienic College of San Carlos, the dank Clinical Hospital, the tiny botanical garden, and the neglected Museum of Natural History, stepchild of the university. He was depressed more than ever before by the cheerless private dwellings and dingy lodging houses in which the students lived, with far more freedom to go and come than was for their own best interest. He was saddened too by the sight of the professors sitting aloof from one another and from the student body, "like owls in a bellry," without any of that spirit, so marked in the English, of working together for a common enterprise big enough to drown out petty jealousies and even bitter personal rivalries.

Cajal had not been able to announce his return, and as he stepped across the doorstep of his house he was filled with misgivings. How had things been at home while he was away being fêted? How had his daughter's illness gone? Had his wife's cheerful letters been written merely to dispel his worries while he could do nothing to help? But all was well. His daughter, though pale and weak, was on the road to recovery. The next day there was a jolly time with all the children noisily crowding about to see the gifts he had brought back from England. To his surprise, he found them a bit blasé about gifts—during his absence the wife of his friend Don Facundo Ruano, sympathizing with the children and their mother in their month's battle with illness, had showered them with presents!

NEW RESEARCHES AND PUBLICATIONS

IT WAS NOT LONG before Cajal settled back into the old routine of quiet hours of solitary, enraptured work in his laboratory. The

Explorer of the Human Brain

problems he was grappling with were of ever increasing complexity, for his inquiries had now taken him into the medulla, the pons, and the thalamus

By adroit use of the same method that had proved so rewarding with relatively simple structures—the method of Golgi, applied to animals in various stages of embryonic development—Cajal reaped the same success as before, finding that his laws of contact and of dynamic polarization prevailed as much here as in the nervous centers investigated earlier. This is his general summing up

The well-known philosophical dictum “Everything is one and the same” applies particularly to the structure of the nerve centers. Led by motives of rigid economy, Nature loves to repeat herself. If it were not for these fortunate uniformities in life, science would not be possible. The logical mind derives a measure of comfort in finding that the organizing principle of life adopts the same method for the same ends, and, in this, man’s hunger for simplicity and unity is somewhat appeased. “Unity of plan with infinite variety of form” is Nature’s watch-word. Like an architect, she conforms to the general lines of a certain style but reserves to herself the right to vary the ornamental touches indefinitely. As a result of this unending variation, the task of the investigator is far from tedious or monotonous. For it is by just these unexpected and ingenious adaptations with which Nature modifies each individual of her creation, without violating her general rules, that curiosity is fed and the sacred fire is kept burning in the mind of the scientist.

Unfortunately, I reached the mine a little too late for discoveries of the first rank. Edinger,⁹ van Gehuchten, and especially Kolliker and Held had been there before me in successfully applying the method of Golgi to the structural analysis of the nuclei of the medulla oblongata and the pons. Thus I had to glean in a reaped field. Still, I did gather something. It was an exacting, unassuming piece of work of perfecting, amplifying, and describing minor details, considerably more laborious than brilliant.

⁹ Ludwig Edinger (1855-1918) German neurologist.

Of how much of Cajal's work can this be said! Yet how significant for later research were these same unspectacular details garnered with such indefatigable patience

The years 1894 and 1895 saw a number of publications of interest to specialists in histology and to anatomists of the nervous system. These years brought the fruits of many conjectures and interpretations on Cajal's part that later investigations and the rapid advance of histology, bacteriology, and embryology were fully to substantiate. Other shrewd guesses had to be discarded as not borne out when checked by the improved staining methods of later years, which made more exact visualization of delicate processes possible to a degree that could not have been realized by the earlier procedures. Many of these improvements were the outcome of Cajal's own struggles with the methods in vogue in his day.

In 1894 Cajal attended the International Medical Congress held that year in Rome. He discussed before the members the morphology of the nerve cell and brought out for the first time the fact that intellectual power depends not on the size and the number of the cerebral neurons but on the richness of their connective processes—the complexity of the association areas of the brain—a fact now established as one of the fundamental principles of psychology.

He had sent to the Congress his first theoretical work, *General Considerations on the Morphology of the Nerve Cell*, in which he had elaborated on this thesis. This monumental study dealt with the laws governing the evolution of the nervous system of animals and included a consideration of which of the nerve centers have, throughout the centuries of evolutionary development, remained relatively flexible and able to adapt to the changing and more complex demands of the higher forms of life, and which centers have been, so to speak, petrified into automatic response and thereby finished so far as further development is concerned. His observations led him to the conclusion that with the nerve tis-

Explorer of the Human Brain

sue, as with physical structures in general, the history of the individual repeats the history of the race

A second general deduction was that, in all vertebrates, two nervous systems exist side by side. The first, he said, is the sensory system, which receives impulses from external and internal sources and transmits them to spinal cord and brain. This has finished development in *kind* and grows only in *degree*, becoming more extensive in the higher vertebrates but not essentially different in its nature from the sensory system of lower animals. The second system is the gray matter of the brain, which is far from finished and goes on eternally perfecting itself, not only in extension but also in the form and structure of its convolutions.

A third important conclusion was that the neurons of the higher vertebrates show their advanced stage of progress by the form and the length of their new processes and the multiplicity of the connections between cells.

The fourth conclusion, resulting from a comparison of the relative shape and abundance of the connecting cells between axons and dendrites in the higher and the lower vertebrates, was that intellectual power—even talent and genius—depends not on the number of the neurons of the brain or on their size, but on the richness of their connections with other cells, the complexity and the intricacy of the association pathways of the nervous system as a whole and of the gray matter in particular. A large amount of gray matter in the brain of man or animal indicates such richness of connection and therefore higher intellect. This had been suspected by such leaders in the field as Meynert and Flechsig,¹⁰ but now it was overtly demonstrated.

Another shrewd guess, thoroughly substantiated by the concept of the conditioned reflex of modern psychology, was the idea that adaptation, dexterity, the perfecting of a skill through practice—such, for instance, as typing and violin-playing—come as a result

¹⁰ Paul Flechsig (1847-1929) Alienist in Leipzig

of a gradual thickening of the nervous pathways involved in the performance of the act, or the formation of new cell processes the actual growth of new dendrites and the extension and branching of new axon collaterals, making connections between neurons that formerly were completely separated from one another

The general laws underlying such an evolution seemed to Cajal to be (1) conservation of material—invariably the shortest path between two related regions was made use of, (2) conservation of time required for the transmission of the nervous impulse, and (3) conservation of space. In all his generalizations Cajal kept close to the actual facts he had himself observed and did not let himself be tempted into the inviting field of pure speculation and theorizing.

In another work of the same period he did not show such restraint but let his imagination run riot. Yet even from this, some well-founded, original, and useful concepts emerge—such, for example, as the theory of the neural avalanche, which holds that every sensation received by the peripheral sense organs is intensified progressively as the impulse approaches the connecting stations of the central nervous system, just as an avalanche gains momentum in its surge downward from a mountain peak to the valley below. This thesis was later borne out by modern psychology and contributed much to the understanding of the physical basis of such abnormal mental states as hallucination.

In 1896 Cajal's activity rose to fever pitch when he returned to the study of the retina, one of his most abiding interests. The new contribution was of an argumentative nature, intended to dispute the theories of certain scientists who were trying to resuscitate the old concept of an interneural network. To refute his opponents, he marshaled an array of new facts derived from his own discoveries. While disproving the belief held by men of the opposing school that there is *fusion* between dendrites and between dendrites and axons, he proved these seeming unions to be optical illusions or the effect of the reagents used rather than realities, and

Explorer of the Human Brain

showed by his own demonstrations on the retina of birds clear evidence of neural *contact*

Cajal next plunged into a study of tumors and cancer and of the methods then in use for staining tumorous and cancerous tissue in an effort to arrive at an exact medical diagnosis. He made noteworthy contributions with regard to skin tumors and the defenses the body sets up upon its invasion by malignant new growths. In the same year he published a paper showing the defensive function of the platelets of the blood of lower vertebrates, a protective action like that of the white blood cells, which attack the invading harmful organism by engulfing it, literally eating it up.

USE OF EHRLICH'S METHYLENE BLUE

FOR MANY of his researches of the productive year 1896, Cajal turned from Golgi's silver stain to the staining method devised by Paul Ehrlich. By this procedure the nerve cells can be made to stand out sharply under the microscope, stained a deep blue. Since the stain contains no poisonous chemicals, it can be applied to the tissues of living animals without causing their death. Emboldened by his first success in using Ehrlich's method, Cajal decided to apply it to a detailed study of the spinal cord, the cerebellum, the cerebrum, and the hippocampus of various species of mammals. By improving on a modification of Ehrlich's stain devised by the German scientist Bethe,¹¹ he managed to get sections that showed these structures fairly well.

One of the compelling reasons why he felt he had to succeed with Ehrlich's methylene blue was his eagerness to check, on the living animal, the facts shown by the less dependable method of Golgi when applied to dead tissue. For although many scientists

¹¹ Albrecht Bethe (born 1872) German physiologist, became professor of neurology at Frankfurt am Main in 1915.

did accept his demonstrations of nervous structures as revealed by Golgi's stain, others argued that deposits of silver chromate might make the structures look as they did and that they might not really be arranged as they appeared to be. Cajal was quite sure that Ehrlich's blue would substantiate his former findings beyond a doubt and thus sound the death knell of the reticular hypothesis, which seemed to be so slow in dying. But he had to do over again all the work he had already done with the silver stain. To accomplish this with Ehrlich's method took almost the whole of 1897. His efforts were completely successful. He not only re-proved the proved but extended his researches to indisputable demonstrations of the actual structure of the nerve cells of the cerebellum, the cerebrum, and the hippocampus—all he had set out to do.

SOCIAL CONTACTS IN MADRID

DURING ALL THESE EARLY YEARS in Madrid, Cajal's teaching and research had gone on in their accustomed way, interspersed with a few social occasions at which he met some of the political and educational leaders of his time. Castelar was one of them. Cajal had been an enthusiastic supporter of Castelar during the Revolution and it was a great moment for him when he was introduced to the "tribune of the people" by one of his colleagues, J. Gimeno Vizarra, a professor at the University of Zaragoza and editor of the republican daily newspaper, *Diario de avisos*. The party at which Cajal met Castelar was held at the former president's home in Madrid, an elegant house furnished with discriminating taste. The mansion of this man of the people could well have been the palace of an aristocrat of the monarchist regime. And Castelar's demeanor was equally aristocratic. Cajal gives a sharply drawn portrait of him.

Like nearly all great men of ability, Castelar was short in stature. He showed the obesity of the gourmand, his head was round and bald,

Explorer of the Human Brain

his color swarthy, his eyes large and dominating, his face clean-shaven except for an imposing mustache in the style of Victor Emmanuel, his voice strong and high-pitched, but when he spoke he was transfigured and acquired unsuspected elegance and distinction. As those who heard him will remember, Castelar was not only the artistic, solemn, and somewhat theatrical orator of the parliamentary debates—he was also a facile, delightful, and picturesque conversationalist. He might not always convince, but he always fascinated and charmed. His co-religionists heard him enraptured, and apparently they were wholeheartedly convinced by all he said. Eloquence is always right. Lulling them with his trills, the Spanish canary (as Taine disdainfully called him) inhibited every effort at criticism and almost even the faculty of thought itself.

I too was ecstatic before that torrent of sonorous words, which sometimes as they met and combined in synthesis, comparison, or contrast proclaimed unimagined splendors. Through that head, overflowing with imagery, the great figures of literature and of history had passed, and there had passed there too, leaving an ineffaceable trace, the romantic breath of Chateaubriand, Lamartine, Victor Hugo, and Michelet.

Upon presenting Cajal to Castelar, Gimeno mentioned the fact that Cajal was a high priest of the world of the infinitely small, a worshipper of those tiny cells of which all living things are made, and a worshipper, too, of the great genius of Castelar.

"You do well," said Castelar to Cajal, "to devote yourself to the study of the cell. Life is a secret and the cell deserves our attention, since we carry it within us and it often influences our actions."

Cajal was tempted to reply: "No, it is far more than that. Those tiny cells that hide the mystery of life are the whole man in his two aspects, mental and physical. United by the division of labor imposed by the body, they react to the stimuli received from without and within, thereby giving us the illusion that we are free, masters of our fate, but actually performing our actions completely by their own inexorable laws." At this period, Cajal was an almost

complete materialist but, respecting Castelar's more spiritual outlook on life, he repressed this thought

He was intrigued by Castelar's manner as he walked about among his guests, his tone of dignified authority shot through with flashes of wit—a wit that was sometimes biting. In one of his remarks Castelar sharply criticized Salmerón,¹² like himself one of the presidents of the short lived Republic

Suppose, said Castelar, that I put poison in the goblet. So long as it is there we are in no danger. But don't drink it for that will be the end of you. Well then, that palmt Salmerón is the deadly poison of the republican banquet. So long as he stays outside, there is no danger but as soon as we take him in we say goodbye to the new republic the orderly state we all long for."

Cajal was disillusioned. Still he thought, though Castelar may be humanly guilty of some few prejudices and some unjustifiable pettiness nevertheless he is a magician of words, a true patriot, and politically incorruptible. He expressed this judgment to Gimeno on their way home.

Gimeno smiled tolerantly. Then he said

"Friend Ramón, I share your enthusiasm. There is no doubt that, with his great ability to win the favor of the army and the conservatives, Castelar might be able to establish an orderly, stable republic. But don't be deceived. No one here has clean hands. Not even our leader, though he is less contaminated than most. But Castelar is a spendthrift, burdened with debts and harassed by creditors, many of them unscrupulous men. To pay off one of them, a racketeer who owned a gambling house and was accused of murder, he used his great influence to get him free so that he could flee from Spain. And I could cite other instances."

Frugal, honest, heavily burdened Cajal was astonished. How could a man whose books paid so well, who was a bachelor, and

¹² There were three presidents in one year. Pí y Margall, Salmerón, and Castelar

Explorer of the Human Brain

who was constantly receiving rich gifts from his followers, get himself into such a financial morass, and how could an honorable man use such means to extricate himself?

The man whom Castelar had spoken of so bitterly Cajal knew only in the classroom

. . . [Salmerón] was tall, slender, lean, and a little round-shouldered, with noble features and eager, searching eyes that seemed to look right through one. His high skull was hairless as if the fire of thought had burned its roots, and his whole person radiated a certain attractive simplicity and a goodness and rectitude that would be proof against all temptations

Salmerón was a wonderful teacher, Cajal thought. He used the Socratic method, drawing his students out to express their own reactions and to detect the flaws in their own thinking. There was not a trace of dogmatism or of affectation in him. He taught philosophy, ethics, and logic at the University of Madrid and was especially interested in that branch of philosophy concerned with the means by which man gains his awareness of the world. Yet it was difficult to determine just what Salmerón's own philosophy was. Even his disciples did not know for a certainty. The most Cajal was able to discover was that he had once been an ardent Krausist but had in later years become an agnostic. The German philosopher Krause had taught that God is known to man intuitively through his conscience. He is not a Person, with all the limitations that personality implies. Rather He is an Essence, containing man and the universe within Himself. Krause called his philosophical system "pan-entheism," which means "all in God." According to it, man and the universe form an organic whole made in the image of God. It follows, then, that the ideal society would be one in which the individual man would lose himself, with all his greeds and ambitions, in his care for the well-being, first of his own social group, then of his nation, then of all mankind. Differences would vanish as the inherent identity of all men

dominated over their disparity, until in the final unity man would be one with God. The Krausist philosophy had a profound influence on Spain in the latter part of the nineteenth century, though Krause is not now recognized as a philosopher of the first rank, he had very sound views on education, and the impact of these on Spanish life was salutary. He stressed the point that the school should educate the whole man, not merely the intellectual side of him. A reform in this direction had long been a crying need in Spain. For proof, one need only recall the authoritarianism, the overrigid discipline, and the utter lack of understanding. Cajal himself had suffered from on the part of his own teachers in his childhood.

Another professor at the University of Madrid won Cajal's immense regard. Giner de los Ríos, who taught legal philosophy and jurisprudence. Don Francisco Giner was one of the most prominent and influential educational leaders of Spain. He had come to Madrid in 1866 and had done much to further the reforms in education and in prison law introduced by the Revolution two years later. With the accession of Alfonso XII to the throne, the reactionary Orovio¹⁸ was restored to power, and he demanded (as he had done before the overthrow of the Bourbons in 1868) that all professors sign an oath of loyalty to the ruling house and to the Catholic Church. Giner was the leader of the group that opposed this measure as infringing upon freedom of speech and personal liberty. He was at once deprived of his chair at the university and imprisoned, this was one of the first acts of the Restoration. Prime Minister Cánovas had Giner removed from a sick bed at four o'clock in the morning and sent under armed guard to a fortress in Cadiz.

Giner and his followers were soon set at liberty but were still deprived of their professorships. Don Francisco would not take such abuse without a fight. Realizing that nothing was to be hoped

¹⁸ Manuel de Orovio y Echague (1817-83) Minister of Education under Isabel II

for from the Government, he and his circle of disciples set about the enormous task of trying to effect reforms through their own initiative. This handful of jobless teachers formed their own school, the *Institución Libre de Enseñanza* (Free Institution of Education), destined to be of immense importance to the cultural development of modern Spain.

Giner was a man of great patience and a born teacher, with an admixture of good common sense untainted by personal self-seeking. He saw clearly that no permanent progress was possible for Spain without a complete overhauling of her educational system. He knew that education must not only sharpen the intellect of a man, it must mold his whole nature, broadening his sympathies and deepening his understanding of the problems that beset the world. Although the *Institución* had been born as a kind of private university, it soon reached down further and further into the more elementary levels, for it was there that its reforming power could touch the largest number. The school was henceforth to be, not a machine to grind out information without clear relation to the vital issues of life, but an environment that would inculcate good will, human fellowship, enjoyment of games and sports, love of beauty, and appreciation of the arts, as well as a source of instruction in the basic facts and skills necessary for earning one's daily bread.

Gradually the influence of the *Institución* was felt in the official universities. And this was a boon, for they had become mere diploma mills. Although Giner was eventually restored to his position in the University of Madrid, he did not abandon his reform program. To carry the work from the elementary and secondary levels up to the university plane, State funds were essential. But the reformers were determined that if these were provided, it must be with no strings attached, or, at least, without the political domination that had been the order of the day before the *Institución* had come into being. How was this to be accomplished? To plunge between the two horns of the dilemma, it was finally de-

[178]

cided that the Government should hand over the needed money to an autonomous committee of eminent scholars, giving them absolute power to plan and direct the university curriculum. In describing this reform the contemporary Spanish historian Salvador de Madariaga says this "As if clearly to signify that the new institution was to be run under strict scientific direction, untainted by politics, the committee was presided over by Dr. Ramón y Cajal, the famous anatomist to whom modern neurology owes its greatest inspiration" * Giner's work had indeed borne rich fruit.

But this was to come in later years. In the early days in Madrid, before Giner even knew him, Cajal often went to his classes, and once while there he brought up the question of heredity and of the cause of death. He raised the point that natural death is unknown among protozoa and microbes. It seems to be the price higher organisms have to pay for their more intricate structure. This very complexity, in turn, is the result of the necessary division of labor among the body cells—the outcome of the early separation of the various groups of specialized cells from the germ cell, which itself is virtually immortal, transmitting the characteristics of the species from one generation to another.

This idea, now accepted as a matter of course, was then revolutionary. It seemed to have all the earmarks of scientific paradox when propounded to this group of lawyers, and they looked at Cajal with astonishment.

"Who does this fellow think he is," their glances seemed to say, "to express such absurdities before the master?"

But Giner—though, as has been said, he did not yet know Cajal—defended the concept and showed that he had read even more than Cajal in the works of Weismann¹⁴ and the other proponents of the idea.

* From *Spain*, by permission of Creative Age Press, Inc., New York, and Jonathan Cape Limited, London.

¹⁴ August Weismann (1834-1914) German biologist, proponent of the doctrine that acquired characteristics are not inherited.

Besides being a remarkable teacher, Giner was a fine orator, though not like Castelar a theatrical one. His speeches were masterpieces of logic, precision, and restraint. One day Cajal witnessed an incident that struck him as being the ultimate in modesty and intellectual honesty. Giner's lecture had been carefully prepared, as always, but after fifteen minutes his thoughts and expression seemed to lose their accustomed clarity and vigor. The students were beginning to think he might be ill when he broke off suddenly with the words "I cannot go on, gentlemen. There is so much material on this subject that it has muddled my memory and I am unable to present it clearly. We never talk better than when we have studied little, or worse than when we have devoted many morning hours to the painstaking preparation of a lecture. So let us leave the subject for another day." This observation found a sympathetic echo in Cajal. He says "For myself, like him a galley slave to the oar of the daily lesson, I am never more fluent than when, after a refreshing night's sleep, I improvise a lecture without consulting with anyone." But most professors would think themselves disgraced if they had to present to their students the spectacle of not being able to fill in their hour of lecture time on the topic of the day. Most would carry on even if their talk were mere rambling and mouthing rather than admit the truth.

EDITOR AND ACADEMICIAN

IN 1897, at the cost of great personal sacrifice, Cajal established his second journal, the *Revista trimestral micrográfica*.¹⁵ His aim was to get his discoveries published quickly without having to wait on the convenience of foreign editors. Another purpose of the *Revista* was to stimulate zeal for original research on the part of his students, whose worth-while contributions were published

¹⁵ *Trimonthly Micrographical Review*

in it. Incidentally, it served as a stimulus to Cajal as well and in it he announced most of his discoveries until 1901, when the annual review *Trilces del Laboratorio de investigaciones biológicas* was founded. The first number of the *Revista* appeared in March, 1901. Cajal had written almost all of it himself. Later he had many excellent contributors among them his brother Pedro, now a professor of histology in Cadix.

On December 5, 1897, Cajal was made a member of the Royal Academy of Exact Physical and Natural Sciences of Madrid. His election at that moment was due to an amusing incident. One of the members of the Academy, when on a trip to Berlin, was asked by the great Virchow, "What is Cajal doing now?"

The embarrassed academicians were overwhelmed with confusion that such a famous man should be interested in the work of a fellow countryman of his of whom he had never even heard. So when he returned to Spain, he made it his business to find out who the Cajal might be. He did find out from the astronomer Don Manuel Molino, and eventually it was proposed that Cajal should become a candidate for a vacancy in the ranks of the Academy. So Cajal used to say laughingly that he was nominated by Virchow and Don Manuel.

Cajal now elected had to give an inaugural address. In 1897 he prepared for this purpose his now well known work of advice to young researchers, *Reglas y consejos sobre la investigación biológica* (Rules and Counsels on Biological Research). This was intended to serve not only as a guide but also as an incentive to boys of scientific bent to engage in pure research, by which they might bring new honor to their native land, hitherto so backward in this field. Cajal did his utmost to make laboratory work sound attractive, and his *Reglas* glow with the patriotism that was one of his deepest emotions. His speech was a great success, and the first printing of his book was soon exhausted. A

Explorer of the Human Brain

friend of his, Dr Lluria, reprinted the *Reglos* at his own expense and distributed a large edition free of charge among the students of the Spanish universities

In spite of his eagerness to promote the cause of pure research in Spain, Cajal never minimized the almost insurmountable obstacles that lay along that rugged road. He himself had wrestled with these too long to be blinded by an easy optimism. His estimate of the toll research exacts and the rewards it offers are summed up in these words—in a sense, an article of his faith: “Nature is hostile to us because we do not know her, her cruelties are her revenge for our indifference. To listen to her inmost heartbeats with the fervor of passionate curiosity is to decipher her secrets, to turn the ireful stepmother into the tenderest of mothers.”

By 1897, honors had been showered upon Cajal from all sides. He was elected to membership in the Royal Academy of Medicine in Madrid after winning the Rubio Prize awarded by that Academy earlier in the same year for his textbook *Elements of Histology*. (He had already received the Fauvelle Prize from the Society of Biology in Paris.) In 1895 he had been made a corresponding member of the University of Wurzburg, at the suggestion of his old friend Kolliker, and some time later he received the honorary degree of doctor from this same university. Meanwhile he had become a member of similar societies in Vienna, Rome, and Lisbon. It was ironically characteristic that his beloved Spain should be one of the last to give him the recognition that had so long been his due. Not only Nature, but native land as well, had proved to be an ireful stepmother, yet one at last to be softened into tenderness.

9. *"Butterflies of the Soul"*

*They will tell you to try to prove you are right, I tell
you to try to prove you are wrong*

—LOUIS PASTEUR

THE SPANISH-AMERICAN WAR

THE year 1898 brought war with the United States. Weakened by civil strife and political turmoil, Spain rallied to her aid absurdly unequal forces. Capital was heart-sick at the sight of it. This struggle seemed to him not only deplorable but insane, brought on by the greed of Spain's industrial exporters, the rapacity of her overseers and employees, and the pride and egotism of her politicians.

Occasion for it was undoubtedly given by hereditary defects in the national character, among others, a mistaken sense of honor and a certain gentlemanly punctiliousness, excusable in individuals but ridiculous in a people, and contrary to the public interest. But more than anything else we were swept to the catastrophe by the disgraceful ignorance of our alternating political parties concerning the real size and efficiency of our own forces and those of the enemy. For although it now seems impossible, deputies, newspapermen, soldiers, and many others at the time honestly believed that our machinery of war in Cuba and the Philippines—vessels of wood and an army of invalids—could measure itself advantageously against the formidable equipment at the disposal of the opponent. A country's misfortune lies not so much in its weakness as in the ignorance of its weakness on the part of those whose duty it is to know.

Explorer of the Human Brain

It is only just, nevertheless, to recognize the fact that such dangerous ignorance of international truths had its exceptions. Apart from the masses, who, having poured out their blood fruitlessly in two cruel campaigns, longed now only for peace, there were, even in the Ministry, men like Sagasta and Moret who saw the abyss into which the blind greed of the wealthy and the unscrupulousness of the army were leading us.

But it is bitter to recall how politicians as far-seeing and intelligent as Moret, Sagasta, and Canalejas, filled with the saving truth, in the critical hour lacked the courage to proclaim it and to fight the opinions of the Crown, the army, and the press. So dangerous and difficult was it to make clear to the eyes of the public, as Pí y Margall did unflinchingly, that a nation of ninety million inhabitants, with immense wealth, inexhaustible resources, and vast military might, was bound to crush a country of the starkest poverty with a population of only seventeen million and drained dry by four devastating civil wars!

The Spanish people were not alone in being maneuvered into the war by the politicians, the army, and the newspapers. American leaders, too, in order to turn attention from popular unrest and a precarious economic situation at home, were busily fostering a policy of imperialism. This was the expedient many of them were clutching at in their effort to gain or to hold political power. Imperialistic expansion, as presented to the people by the press, had two great appeals. First, it would provide profitable markets for the farmers' surplus crops. And second, it would fill the industrial workers' dinner pails by providing jobs for them in a period of widespread unemployment. Many Americans in positions of wealth and influence saw in a foreign war such as this one, with its dramatic crises and its sure victories, an effective way of turning men's minds from their personal troubles and from the reform programs that were sweeping the country, making poor men rebellious and rich men uneasy.

The Cubans had often before this revolted against their mother country, and the United States had been little concerned. But

[184]

this time the American newspapers, particularly those published by William Randolph Hearst, were filled with grim reports of the cruelties practiced in Cuba by the Spanish generals sent to subdue the rebels. Some of the atrocity stories were true, some were not.¹ But all were accompanied by pleas to decent, liberty-loving Americans to support the movement for Cuban independence, at least morally. Mingled with these pleas were the cries for help from American investors who owned plantations and sugar mills in Cuba, property now menaced or despoiled by civil war.

As a result of all this hysteria, the pocket-sized battleship *Maine* was sent to Cuba to safeguard American interests in response to a secret request from the American Consul-General. It appeared in Havana harbor on January 25, 1898, when the excitement over the Cuban situation was running high. On the night of February 15, it mysteriously blew up. More than 260 American officers and crewmen lost their lives. The Spanish officials were accused of blowing up the *Maine*, but to this day the real truth of the matter has not been told. In spite of the surge of public anger that followed the announcement of this event, President McKinley showed clearly that he wanted very much to keep the United States well out of the whole Cuban affair. In fact, he was so bent on his policy of noninterference at this time that Theodore Roosevelt called him weak-kneed, a man with the backbone of a chocolate éclair. Paying little attention to the impetuosity of Roosevelt and his followers, McKinley managed to extract an agreement

¹ In 1878 Cánovas had sent General Valeriano Weyler to Cuba to put down the rebellion. He attempted to do so by a ruthless policy of oppression. In 1897 President McKinley protested the state of affairs in Cuba and demanded that the revolt be quelled. The Queen Regent asked Sagasta to form a new administration. Weyler was recalled to Spain and Marshal Blanco sent to Cuba to take his place. Blanco's policy was more conciliatory and was aimed at the establishment of home rule in Cuba, as advised by Sagasta and Moret. This might have averted the war with the United States but failed to do so because of other pressures brought to bear in Cuba, the United States, and Spain.

from Spain which promised peace in Cuba and a degree of self-government that practically amounted to independence

Yet suddenly and surprisingly, on April 11, without fully revealing to the public the extent of the Spanish promise, President McKinley did an about-face. He asked the Congress for a resolution authorizing him to send troops to Cuba to drive out the Spanish forces. In the long debate that followed this request, the question of Cuba's future status was naturally brought up. Were the Cubans capable of self-government or was the island to be annexed? The Congress voted that Cuba should be independent. The anti-imperialists in the Senate even managed to get through an amendment to the resolution to the effect that the United States disclaimed any intention of exercising sovereignty or control over the island—it sought only to bring peace to it. On April 19 the resolution was passed, empowering the President to send troops to Cuba if that should prove necessary in order to drive out the Spanish soldiers already there. This was a declaration of war and under it war was begun. There was no mention at this time of the Philippines or of Puerto Rico.

The war was over in a few months. On May 1 Commodore George Dewey steamed into Manila Bay with the Asiatic fleet of the American Navy and sank all the Spanish warships that were lying at anchor there. The loss in this first encounter was nine American lives. During the week of June 20-25 an American army of 15,000 men landed at Daiquiri, Cuba. In the first days of July the Spanish blockhouses at El Caney and San Juan Hill, near Santiago, were captured in the only real fighting of the war. Admiral Cervera's Spanish fleet tried to flee from Santiago harbor on July 3 but was destroyed by American warships lying in wait, with the loss of only one American life. On July 17, Santiago—next to Havana the most important Spanish stronghold—surrendered to the American invaders. The Spanish Government sued for peace on July 26 and an armistice officially freeing Cuba from Spanish control was signed at Paris on the twelfth of August. At

just this moment word came that American landing forces had taken Manila, virtually ending Spanish rule in the Philippines. Puerto Rico was then occupied without a skirmish. An overseas empire had been won in ten weeks of actual fighting and with trifling loss of American lives: the Army reported 280 killed and the Navy only 18.

In the final treaty drawn up at Paris, Spain granted Cuba her independence, ceded Guam and Puerto Rico to the United States, and transferred the Philippines to the custody of the United States in exchange for a payment of twenty million dollars. The anti-imperialists in the Senate who had fought hard for the amendment added to the war resolution now saw that they had failed to accomplish their real purpose. Fearing that the United States would henceforth be thrust into interminable wars in Europe and the Far East, they formed a strong bloc against the Administration's policy, which by now had wholly succumbed to the pressure of the expansionists. But they lost again. The ultimate fate of the Philippines was left undecided, and two years later Cuba would have to submit to the hated Platt Amendment, establishing a protectorate over it.

Cajal was vacationing in the country town of Miraflores de la Sierra when he got the news of the Spanish defeat in Cuba. He was staying with his family at a little villa not far from a similar one occupied by his friend Federico Olóriz and his family. Cajal and Olóriz had been spending the long summer days reading, hiking, and playing endless games of chess. Earlier in the summer Cajal had been working on the problem of the intercrossing of the nerves in the optic chiasma and jotting down his observations for later use. The news from Cuba struck him like a blow. In such a world his researches seemed to matter little, and for a time his creativeness was paralyzed by this feeling of futility.

The Spanish newspapers, expressing the stunned bewilderment of the people, asked the intellectual leaders of Spain to analyze the causes of the débâcle and to propose a program to reform the con-

Explorer of the Human Brain

ditions that had led to it. For in spite of everything, underneath the general despair there was a glimmer of hope. An era of renewed faith in reform was beginning, an era known as the Regeneration. Cajal was to make his contribution to the new age in company with such writers as Pío Baroja² and Valle-Inclán.³ In later years he chided himself for his effrontery in entering the political forum. What right, he asked, had a humble laboratory worker to censure social and political actions of which he knew little, and how valid could his proposals be? Many of his suggestions were undoubtedly well-founded, but, as he himself pointed out, the general ineffectiveness of such writings stems from the fact that they are read only by persons of like views, those not in need of conversion.

The first edition of Cajal's autobiography, *Recuerdos de mi vida* (Recollections of My Life), begun in 1901, was written in answer to his country's need after the loss of its colonial empire in 1898. He wrote down an honest account of his successes and his failures in the hope that by so doing he might encourage earnest effort in the young men of Spain. This ultimate goal presented its own dilemma. Cajal was a modest man. His nature prompted him to depreciate his undeniable accomplishments. But to do this would be to defeat his real purpose and to thwart the intense patriotism that had impelled him to write his life story at all. In the *Recuerdos* he laid bare the obstacles that beset the path of every Spaniard who tried to do anything of note in original scientific research. He wanted these obstacles to be clearly recognized so that they might be removed. At the same time he wished to show that hard work, zeal, patience, and perseverance could go a long way toward overcoming them. The autobiography is of unequal merit. Volume I is wholly readable, sparkling with flashes of wit and sharp revelations of Cajal's inmost self. Volume II bogs down under the weight of technical detail that full description of his work necessarily

² Pío Baroja (born 1872) Spanish novelist

³ Ramón del Valle-Inclán (1870-1936) Spanish poet and novelist

When his work was done, the traditional doctrine was fully confirmed. Both methods showed that there is in man and in the other higher mammals a strong homolateral tract (that is, nerve fibers extend from each eye to the part of the brain on its own side), but there is also crossing of nerve fibers at the chiasma. In man, half the fibers of each optic nerve decussate, and half remain on the side of origin. The proportion varies throughout the mam-

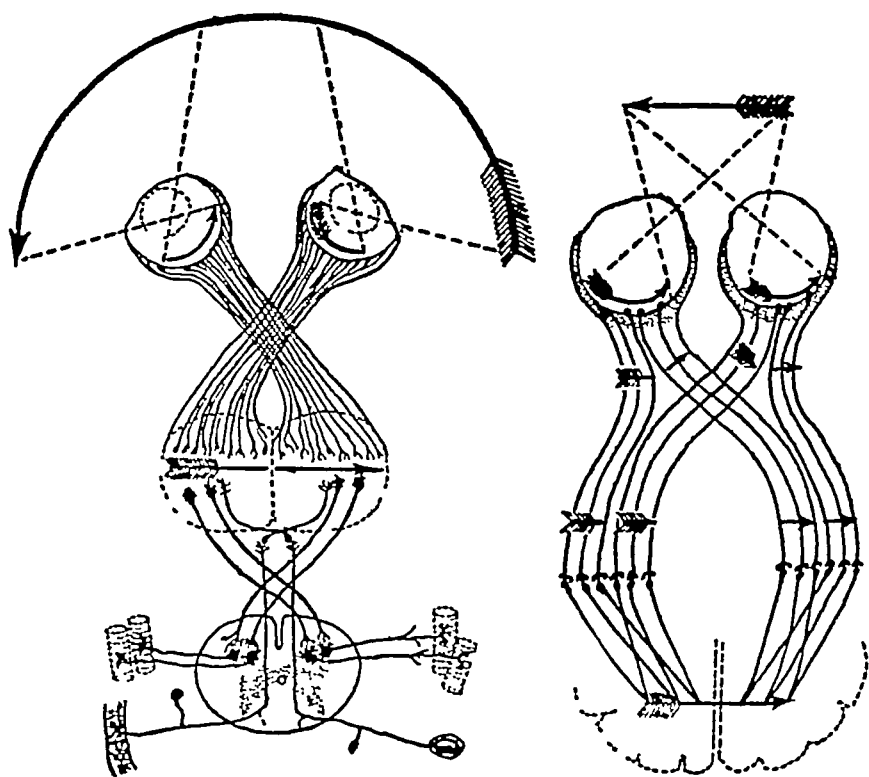


FIG. 4—DECUSSATION AT THE OPTIC CHIASMA. Left, diagram showing the effect of the complete intercrossing of the optic nerves in a lower vertebrate. The two central images form a continuous whole (Panoramic vision). Right, diagram showing the effect of partial intercrossing in man and in other mammals. The central image comprises a combination of the two representations of the object transmitted by the two optic nerves (Common visual field). (Courtesy of Dr. E. Horne Craigie, Professor of Comparative Anatomy and Neurology, University of Toronto, Canada) [190]

Explorer of the Human Brain

Having laid the ghost of the decussations of the optic chiasma, Cajal next attacked the biggest of all histological problems—the anatomy of the human cerebrum, the brain proper. It was generally accepted by the scientists of the time that the differences between the brain of lower animals and the brain of man were quantitative rather than qualitative. According to this view, the superiority of man's intellect would be due entirely to the larger number of its pyramidal cells and the greater complexity of its association fibers. Cajal felt that the differences were more far-reaching. He held that the brain of man differed also in *kind*. There was one way to find out—the microscope.

In this daring venture he ran head on into the deepest of all social and religious prejudices. The most delicate staining methods—and nothing less would do for the intricate maze of the human brain—are effective only when applied to fresh nervous tissue, tissue that is almost alive. But the law did not allow the human cadaver to get to the hands of the anatomist until twenty-four hours after death. By that time the fragile neurons had already undergone considerable change and had lost their affinity for methylene blue or chromate of silver. How could one get around such an obdurate stumbling block?

Cajal found two institutions willing to help—the Foundling Home and the Maternity Hospital. These two establishments did not pay too strict attention to the law, and since the families of unwanted dead children cared little what became of them, the corpses got to him soon after death. Within two years he had autopsied hundreds of fetuses and the brains of children of various ages, dissected while still warm.

His harvest was rich. He discovered new types of neurons with short axons characteristic of the human cerebrum. He made detailed observations of the terminal branchings of the sensory fibers and discovered true pericellular baskets comparable to the elegant nests that had so intrigued him in the cerebellum and the hippocampus. His special aim was next to disentangle the structure of

the sensory centers in the brain. In each one his preparations showed a specific texture, establishing the histological basis for the then much-debated doctrine of cerebral localization.⁸ This, of course, was the work of many years. The upshot of it all was that Cajal proved undeniably that the superiority of the human brain is linked up with its tremendous wealth of neurons with short axons, a type not encountered in anything like the same abundance in the higher vertebrates other than man. These findings are all discussed in detail in Cajal's monumental work, one of the principal works of his life, begun in 1897 and finished in 1904, *Textura del sistema nervioso del hombre y de los vertebrados* (Texture of the Nervous System of Man and of the Other Vertebrates).

VISIT TO THE UNITED STATES

In 1899 while deep in his studies of the human cerebrum, Cajal received a surprising letter from America. Clark University in Worcester, Massachusetts, to celebrate the tenth anniversary of its founding, was inviting five distinguished men of Europe to give a series of summer lectures. Cajal's letter asked if he would give three and enclosed a check for \$600. He was dumbfounded. How had it come about that a Spanish scientist should be thought of in the United States at just this moment? The war was hardly over.

⁸ The determination of the location of the various centers of the brain, also the limitation of the various cerebral faculties to a particular brain center. The brain is divided into large segments, called lobes—the frontal, corresponding in position with the frontal bone, concerned with the control of voluntary movements, the temporal (auditory area) on the outer side and under surface of each cerebral hemisphere, the parietal (largely associational) corresponding in position to the parietal bone, the occipital (visual area) corresponding in position to the occipital bone.

In man, as compared with other mammals, there is an enormous increase in the total quantity of the cerebral cortex and a great increase in the specialization of certain areas. Also there are striking differences in the cellular arrangement of the various cerebral lobes.

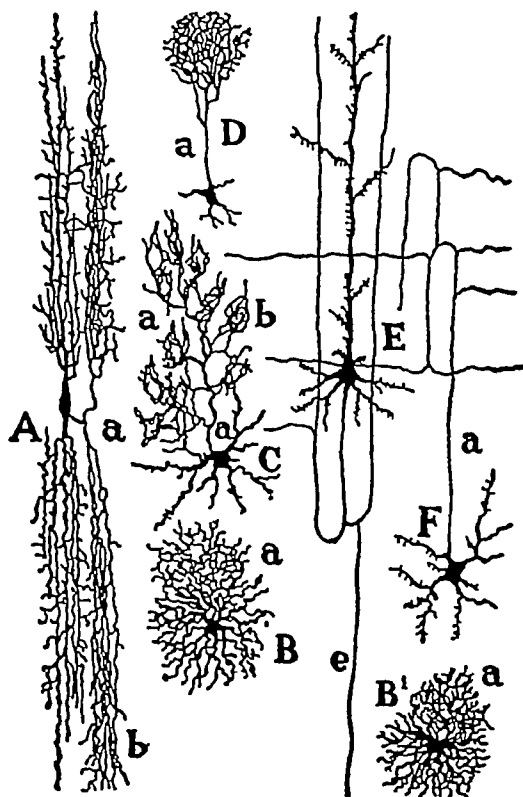


FIG. 5 —DIFFERENT TYPES OF NEURONS WITH SHORT AXONS Found in the cerebral cortex of a child a few months old (Stained by the method of Golgi) A, a two-tufted cell with its axon *a*, B, dwarf cell, C, basket cells, D, cell with tufted axon, E, pyramid with arching collaterals, F, cell with short axon and broad horizontal branches (Courtesy of Dr Francisco Tello, Director, Instituto Cajal, Madrid)

Spain was still smarting from the humiliation of her defeat and the loss of her colonies. Cajal wanted to decline the invitation. He had no wish to go to America in any case and certainly not in this period of international tension. But the Minister of Education, the Span-
[194]

ish Government, and many of his friends whose opinions he valued, all urged him to go. He was far from well. A lingering influenza, or overwork in the laboratory made still more exhausting by nights of sleeplessness when the excitement of discovery was upon him, had worn him out and left him with a heart condition that filled him and his wife with foreboding. But he set out on the journey nevertheless, accompanied by Doña Silveria, who would take care of him if one of his heart attacks should occur.

They went through Paris en route to their ship, which sailed from Le Havre. On shipboard he met the others who had been honored by the same invitation. Dr. A. Mozzo, Professor of Physiology at the University of Turin, Professor E. Picard, mathematician of the College de France. Dr. A. Forel, physiologist of the University of Zurich and Dr. L. Boltzmann, Professor of Theoretical Physics of the University of Vienna. The twelve days' journey passed in delightful conversation.

In June the ship docked at New York in the midst of the most suffocating heat that Cajal had ever experienced. The thermometer soared to 113° F. in their hotel room and was even higher in the streets below. To add to their discomfort, a fire broke out in the hotel at which they were stopping, the main stairways were blocked with smoke and they rushed to a fire escape near by. But Doña Silveria was so much terrified by the insubstantial steps leading down from the little iron balcony that nothing could induce her to set foot upon them. Fortunately, the New York firemen soon had the blaze under control and restored them to safety.

Cajal explored New York thoroughly—visited the Statue of Liberty and Brooklyn Bridge, drove up Fifth Avenue past the mansions of the millionaires, took some fine pictures of St. Patrick's Cathedral, went to the beaches and to Central Park. When shopping in the New York stores for presents for their children, he and his wife heard from many Cuban refugees employed there of the abuses the Cubans had suffered under Spanish rule. They came to realize how the hearing of such stories from the lips of

Explorer of the Human Brain

those who had experienced what they spoke of could well have played a large part in producing the emotional state of mind that had led to the war. The sympathy of kind American men and women who pitied the misfortunes of the refugees had made them an easy prey for both American expansionists and Cuban conspirators, who also had done their share.

Their New York visit ended, the Cajals set out for Worcester. The express train they rode in was stifling hot. They got to Worcester late in the evening and spent a sleepless night trying to relieve Don Santiago's raging headache with cold compresses. It was the Fourth of July. From the streets below their windows a deafening din came up to them—songs, cheers, and the sharp reports of bursting skyrockets. The Spanish wrangles in the bull ring were nothing compared with it, they thought. Speculating on all such demonstrations, Cajal asked himself "Do people raise such an uproar because they are happy, or to make themselves happy?" He decided it was for the second reason. "The lot of the working man in every country is hard," he thought, "and at bottom both the laborer and his brother the brain worker are both supremely weary animals."

The noise ended at dawn and the Cajals got a bit of sleep. Don Santiago was feeling better when he finally announced their arrival to the President of Clark University, Dr. G. Stanley Hall. The president promptly sent one of his professors to the hotel to escort his foreign guests to the college. This energetic young man astonished the Cajals by bringing their trunk and handbags down from their room himself instead of asking the coachman to do it. This, they thought, was democracy *à outrance*.

Their host was Mr. Stephen Salisbury, the rich philanthropist. He was a man of about sixty-five, still a bachelor—from horror, he told them laughingly, of the American woman. The suffrage movement was then gaining momentum in the United States and a courageous group of women, braving the scorn and ridicule of

their compatriots, with a number of the intellectual and moral leaders of the land among them, were struggling to obtain for all women equal rights with men as citizens of a democracy.

The Decennial Celebration of Clark University lasted from the fourth to the tenth of July. There were the usual banquets, receptions, trips to neighboring places, and finally the scientific lectures. Cajal presented a comparative study of the sensory areas of the human cortex—the subject he had been investigating during most of 1898 and 1899. As he always did, he illustrated his lectures with demonstrations of his techniques and with huge wall charts showing the structures under discussion.

When all the sessions were over, the texts of the scientific lectures were printed in a handsome illustrated volume published by the University as a memorial of the occasion. At the solemn closing meeting, letters of congratulation were read from President McKinley and from other prominent Americans, and an address of thanks was given by the President of the University. Finally, the foreign visitors were awarded the honorary degree of doctor of laws, after which they too gave speeches of thanks.

Cajal's impressions of the United States on this his only visit are both revealing and amusing.

The role of more or less illustrious guest is an embarrassing one in America. The people of the United States not only wish to learn from the foreigner, they wish to have his opinion of them. In spite of ourselves we were forced to think up quick answers to such delicate questions as these: "What defects do you see in our educational institutions? What reforms do you suggest to improve them?"

Out of courtesy and proper gratitude for the honor being done us, we could do nothing but praise. I did suggest—with as much tact as I could—some innovations, such as the creation of a laboratory for investigations in bacteriology and another for research in histology and pathology.

I had worse luck than my companions in the matter of interviews. Being a Spaniard, I was the favorite target of the political reporters.

Explorer of the Human Brain

The newspaper women particularly besieged me day and night I was to tell them—a mere bagatelle—the advantages and the disadvantages to be derived from the annexation of Cuba, Puerto Rico, and the Philippines It was like talking of the halter in the house of the hanged!

I did succeed in saving my wife from the women reporters (Typical old maids—fine examples of what Ferrero called the third sex) They were determined to get Señora Cajal's opinion on feminism and on the chances for a campaign in Spain for the emancipation of women

"In Spain," I told them, "we are so backward that our women are still content to be feminine and not feminist. And it seems that is enough for their happiness and for the happiness of their homes"

Cajal was promptly put on their black lists He writes that he was amazed to read in the newspapers what he was supposed to have said on all kinds of issues In spite of the tribulations visited upon him by the "lady journalists," however, he was fair enough not to condemn all American women Though his background debarred him from any sympathetic understanding of the suffrage movement—he thought the suffragists fanatical in both their aims and their methods—he did express admiration for those whom he considered to be truer representatives of American womanhood, the wives of some of the professors, strong, cultured women, good homemakers He praised especially the fine nurses he met in America

After leaving Worcester the Cajals visited Boston and Cambridge Don Santiago was enthralled with the Library of the City of Boston Its completeness and its efficiency delighted him But when he was taken to see its collection of current Spanish periodicals and newspapers, he found it regrettably small Yet the Spanish newspapers that had found their way into America had done their work When showing him the Boston collection, the librarian said, "These carry half the responsibility for the war"

"How could that be?" Cajal inquired

"They provoked us impudently, calling us hucksters, sausage-mongers, cowards Telegraphed, translated, and commented on by
[198]

our press, they stirred up deep resentment even in those who love Spain, as I do "

Cajal was distressed to hear such blame but he had to admit that it was just

Having thoroughly explored Boston and visited Niagara, the Cajals returned to New York to embark for the voyage home In the few days left them before their ship sailed, they visited Columbia and New York Universities and West Point

Rather oddly, Cajal was enormously interested in the development of the phonograph by Edison and his co-workers at Menlo Park A personal element was involved here as well as purely scientific interest in a new invention and its improvement For Cajal himself had been devising a scheme to improve the talking machine The Edison phonograph had created a sensation in Madrid in 1896 The cult of recording spread far and wide, even ensnaring Cajal, who had little love for music—he had found that the phonograph made the long winter evenings very pleasant The chief defect in the early machines was weakness in volume—a feebleness of tone that had led Letamendi to call them "talking rabbits " Cajal had thought up a way to correct this without getting the screechy sound that so often accompanies increase in volume He hired a mechanic to make a model using his new system of recording, but the model was so inexpertly made that the effect was disagreeable though the principle on which it was constructed was the right one He put the model away and forgot about it In America he now saw fine phonographs for sale that embodied the invention he had incubated in his own mind The moral he drew from all this is that it is better to plow one's own furrow and not to waste precious time reconnoitering in another's field

THE MOSCOW PRIZE

IN AUGUST, 1900, the Moscow Prize was bestowed upon Cajal by the Thirteenth International Medical Congress then in session in

Paris It was to prove of the greatest importance to his scientific career This award of 5,000 francs had been instituted by the Moscow scientists to commemorate the Twelfth International Medical Congress held there in 1897 It was to be given to the person whose work in scientific medicine was considered the most helpful and suggestive to the medical profession within recent years The decision as to who should receive it was left to an international committee made up of leading medical men from several countries Upon the nomination of Dr Albrecht of Vienna, Cajal's work was unanimously voted to be the most significant accomplished during the three-year period between the Moscow and the Paris sessions of the Congress As an added gracious touch, it was decided at the same time that the next medical congress—that of 1903—should be held in Madrid Spain and Latin America were jubilant The choice of Cajal was looked upon as a sort of racial triumph

Cajal was not in Paris to receive this unexpected honor in person He was quietly pursuing his researches on the cerebral cortex in the cottage he had built at Quatro Caminos, a district near Madrid In the years just past he had been sick in body and spirit. He longed for the country He envisioned a little house with a walled garden from which one could see the peaks of the Guadarrama Mountains and an expanse of sky unmarred by smokestacks and chimney pots In such a place he felt he would be able to do his work in peace So he had his house built at Amanuel It had a flower garden, a grape arbor, a small conservatory, and a little orchard beside a canal Terraced lawns spread out to the warming sun All his savings went into this home But his instinct proved to be right Sun, fresh air, woodland, and mountains made his health better than it had been for a long time and changed his melancholy into a cheerfulness he had not felt since his youth

The money from the Moscow Prize helped fill his flattened purse Though he rejoiced in the honor of it and the opportune bonanza, he was a little rueful at the thought that answering the flood of congratulations he received would take up a month's time

Not that he was ungrateful for the kind wishes that came to him, but he felt the urgency of much work to do. The tributes came from all sides. His old friend the journalist and author, Don Amalio Gimeno, wrote his life story for the *Heraldo*. Congratulations came from Queen María Cristina and from her Prime Minister Don Francisco Silvela. The queen decorated him with the Grand Cross of Isabel the Catholic, the insigne being paid for by his students of the School of Medicine. A short time later, he was decorated with the Grand Cross of Alfonso XII and was made a Counselor of Public Instruction.

The honor that touched him most was the congratulatory meeting assembled for the occasion at his own university. In answer to the praise lavished upon his embarrassed person, Cajal read his speech of thanks, he was sure his emotion would drive every thought out of his head if he tried to speak from memory. He addressed those students who, spurred to longing for a national intellectual revival by the recent military rout of Spain, looked to him for leadership in the cause. This is the appraisal of himself that he read to them so earnestly that day.

You have made kind references to the quality of my intellect and my unusual aptitude for the cultivation of science. In all that, you have displayed more good will than justice. I am indeed not a scholar but a patriot. I am a tireless worker rather than a creative architect. The story of my accomplishments is simple. It is the story—a quite ordinary one—of a will determined to succeed at any cost to itself. When in my boyhood I saw with sadness to what a low estate anatomy and biology had fallen in Spain, and how few of my countrymen had won a place in scientific medicine, I firmly resolved to abandon my artistic aspirations forever, giving up the golden dream of my youth, and to march boldly into the international strife of biological research. My strength was patriotism, my guiding star the exaltation of the academic gown, my goal the increase of the sum of Spanish ideas circulating in the world. I sought to garner respect and sympathy for our science and to collaborate in the magnificent enterprise of discovering Nature—which is the same as discovering ourselves.

Explorer of the Human Brain

After enumerating the signs already present of a renaissance of Spanish intellectual life, he urged them "Let us love our country even if it is only for her misfortunes!"

NEW RESPONSIBILITIES

IN THIS SAME YEAR, 1900, Cajal was appointed director of the newly founded Alfonso XII National Institute of Hygiene. As was often to be the case when unsought honors came to him, his first impulse was to refuse this one. But in 1900 a plague was raging in Portugal which threatened shortly to spread to Spain. The emergency demanded that both his modesty and his love of work in solitude be brushed aside. He at once set about organizing the several sections of the institute as well as he could and as quickly. The chief task was to find competent section heads who would be willing to serve for the small salaries the State would pay them. Cajal tried hard to avoid favoritism and to choose those candidates who clearly, by all the objective evidence at hand, were best fitted for the positions to be filled. The Institute was soon to grow and prosper, becoming more important scientifically and more efficient as the years went by.

The Spanish press now suddenly did him an excellent turn. By its exaggeration (he says) of the difficulties under which he had made his discoveries, the poverty of his equipment, and the meagerness of his material resources, the State was stimulated to lend a hand in the rebirth of Spanish science. Don Francisco Silvela proposed to the Cabinet that an institute of scientific research be founded in which Cajal could carry on his work with adequate facilities and free from financial worry. The founding of such an institute was authorized by the Cortes in 1901. To this end, 80,000 pesetas were appropriated for buying equipment and establishing a laboratory. The director (Cajal) was to have an annual salary of 10,000 pesetas. Cajal thought this salary too high and the follow-

[202]

ing year had it reduced to 6000. The new institute was set up in the museum of Dr. Velasco and was named the Laboratorio de Investigaciones Biológicas (Laboratory of Biological Research).

Nothing could have pleased Cajal better than the founding of this laboratory. He now had up-to-date equipment. He no longer had to struggle against running into debt through the purchase from his own pocket of the books and materials he needed and for the publication of his cherished *Revista trimestral*. The *Revista* now became a new annual magazine entitled *Trabajos del laboratorio de investigaciones biológicas*. The new review had good paper, fine pictures, and could be made as ample as the worthwhile material it hand permitted. It became an important organ for the publication of Cajal's own researches and those of his assistants and students. The State had made a good investment in thus setting him up in business for himself.

In 1903 the International Medical Congress met in Madrid, as had been planned three years before at the Paris meeting. Naturally the budding Spanish scientists working under Cajal wanted to make a good showing, and activity rose to a frenzied pitch in the Laboratorio. As president of the section on anatomy and anthropology of the Congress, Cajal spent his days and evenings helping his students finish their studies and write up their papers. In the same year he published fourteen articles of his own—some of book length. Though this was the peak year of his scientific productivity, he managed to steal a few weeks in the summer for a trip through Italy with his wife and sisters, stopping at Genoa, Milan, Turin, Pavia, Venice, Rome, Pisa, and Naples.

THE NEW TRANSPARENT STAIN

THOUGH THE ARTIST in Cajal responded to the beauty he saw everywhere in Italy, the scientist in him was not submerged. Before leaving for this trip he had been trying to invent a new stain-

Explorer of the Human Brain

ing method, one that would procure the clear revelations possible with chrome silver but transparent, so that the inner structure of the neuron could be seen. With the chrome-silver method the nerve cell shows up deeply stained but opaque and one can get no idea of its intimate constitution. While in Italy his thoughts kept swinging back to the tormenting problem he had set himself. Hypotheses raced through his brain as he looked at the masterpieces in the art galleries or at the serene loveliness of the Italian landscape. One day when he was on the train on his way home, a brilliant idea flashed across his mind. A simple thing. The effect he was seeking might be achieved by the use of hot, free silver nitrate. The notion held him like an obsession. He longed for the moment when he would be back in his laboratory to put it to the test. The beauty of the Côte d'Azur whisked by without his throwing it a glance.

Once back in Madrid, he hid himself in his laboratory the first hour he could manage it. He fell upon his experimental animals (he says) like a beast of prey. The steps of the new procedure were these. Pieces of nervous tissue were immersed in silver nitrate and heated for four days. The amount of silver salt in the block was then reduced by a bath of pyrogalllic acid that had been kept in a dark place. The tissue block was then washed, bathed in alcohol, and encased in celloidin. Finally, it was cut into sections for microscopic study.

From the very first, his efforts met with success. The neurofibrils—delicate threads that run through the neuron in great numbers from the tips of the dendrites to the tip of the axon—stood out sharply, outlined in brown, black, or brick-red—and perfectly transparent. Another great advantage of the method was that when it was carefully carried out it gave consistently good results.

Cajal could not sleep for excitement. Nor could van Gehuchten when he first heard of the new stain and tried it out. In Spain the method was successfully used by Cajal's brother Pedro and by his pupil Dr. Francisco Tello, who made several discoveries through

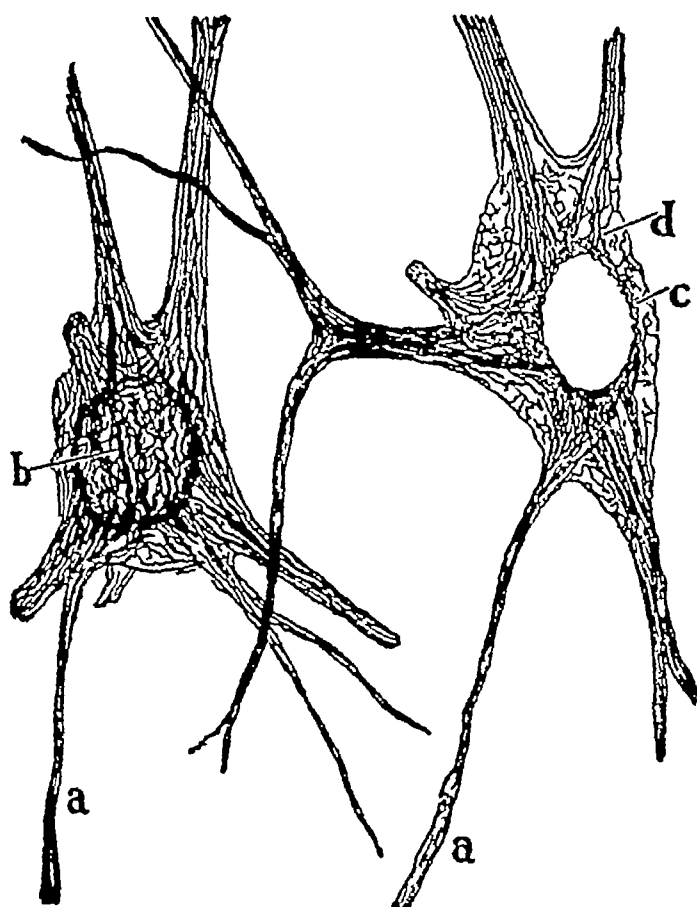


FIG 6—SECTION STAINED BY CAJAL'S REDUCED SILVER-NITRATE METHOD Large cells of the cortex of the anterior quadrigeminal tubercle *a*, axon, *b*, plexuses seen superficially, *c*, perinuclear plexuses, *d*, plexuses of neurofibrils (Courtesy of Dr Francisco Tello, Director, Instituto Cajal, Madrid.)

it, one of the most important of which was concerned with a change that occurs in the neurofibrils of certain animals during hibernation

Soon after Cajal had devised his reduced silver-nitrate stain, a German scientist arrived at a similar procedure, one especially

applicable to study of the human brain. Cajal's variant was better suited to investigation of the structure of the nerve centers of lower vertebrates in various stages of development. Today many varieties of the method are known and used. One of them was of signal service in the discovery of the spirochete of syphilis.

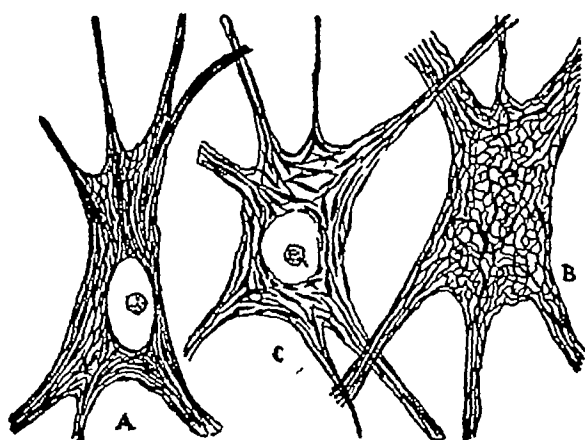


FIG 7 —EFFECT OF COLD ON THE NEUROFIBRILS (Stained by Cajal's reduced silver-nitrate method) A, fine neurofibrils at 25 degrees, B, beginning of thickening at 25 degrees, C, great thickening in a few hours at 10 degrees (Courtesy of Dr Francisco Tello, Director, Instituto Cajal, Madrid)

The perfecting of the transparent stain was bound to lead to new investigations.

For the biologist [says Cajal] every advance in staining technique is like gaining a new sense with which to explore the unknown. As if Nature were determined to keep hidden from our eyes the marvelous structure of the cell, this mysterious protagonist of life is obstinately concealed in the double invisibility of smallness and homogeneity. Structures of amazing complexity appear under the microscope colorless, uniform, and as simple in architecture as a mass of jelly.

Only by making these seemingly identical entities stand out from one another by a selective stain can the histologist even begin his analysis of them. He must (so to speak) transform the colorless beehive of cells into painted butterflies—"butterflies of the soul" Cajal once called them. The reduced silver-nitrate formula was therefore the fulfillment of the histologist's dream: it could be widely applied, it produced transparent coloration, it was simple to use, and it had exquisite selectivity for the neuron. In addition, it had the advantage of being quick, achieving the desired results in far shorter time than other known procedures. By its use Cajal rapidly confirmed many matters concerning cell structure that had formerly been only hypothetical or controversial. During all of 1903 and 1904 he threw himself into this task. Papers on his findings came pouring forth with unabated regularity.

The first report had to do with the architecture of the neurofibrils. His reduced silver nitrate showed that they make up a network of threads, not a system of threads independent of one another passing from the cell body into the processes, as had been proposed by the contemporary anatomists Apathy, Bethe, and others. Aided by Dr. Tello, he went further: he showed that the structure of the neurofibrils varied under different types of stimulation. Better still, the new formula showed up brilliantly the basket endings and the mossy and the climbing fibers in the terminal branchings of the nerve processes. And it did this without the use of any tints! Ended forever, then, Cajal thought, would be the arguments of the proponents of the reticular theory, who had opposed the interpretation of many of Cajal's earlier findings on the ground that the silhouettes produced by his chrome-silver method did not represent the actual arrangement of the cells but were artifacts produced by the stain itself.

Following the pattern of his earlier work, Cajal applied the new stain to fetuses and newborn animals of many species. As he had found before, he now found again that the nerve cells and fibers

stained more intensely and uniformly in unborn or very young animals than in animals more fully mature

Having learned all that the reduced silver method could teach him of the structures in healthy animals, he turned to the study of these same cells and fibers in various conditions of disease. He hoped his discoveries along these lines would contribute some help in the diagnosis of certain pathological states difficult to detect in any other way. He soon found much of interest concerning the effect of rabies on the nerve centers of animals.

THE "TEXTURA"

NINETEEN FOUR was a year of fulfillment and culmination. Cajal at last finished the tremendous textbook he had been writing for five years—the classic *Textura del sistema nervioso del hombre y de los vertebrados* (Texture of the Nervous System of Man and of the Other Vertebrates). It contained 1800 large pages and 897 original illustrations. In this voluminous book he rounded out the work of fifteen years of research. Only a small first edition was printed and the copies were sold at a low price to attract sales. When all was checked off, Cajal had lost 3,000 pesetas (about \$540) through its publication. It was translated into many languages, notably into French by Dr. Azoulay, Cajal's official French translator. The French edition appeared in 1911 and had been brought up to date, covering all the facts Cajal had discovered in the years since the publication of the original Spanish text.

Though it brought him little gold, the *Textura* was rich in inner rewards. It is revealing of the man that he felt its reception was all he could wish.

The object of my work was, above all else, to give myself a lasting stimulus to creative work. Foreseeing the hours of discouragement and fatigue that lay ahead, I wished voluntarily to give up my liberty by making a pledge of honor to the public. Then, too, the book was an

expression of epoch too human not to be forgiven. Fearful of oblivion and unsure of having followers able to carry on my work, I was determined to unite in one integrated whole the important findings of all the neurological papers I had published at home and abroad, filling in the new points as the work proceeded. But most of all I wanted my book to be—forgive me—a trophy laid at the feet of the dying science of Spain and an ardent love offering made by a Spaniard to his country, a country so much despised by the world.

In 1905 Cajal's researches graduated to the study of the adult structures of the nerves of mammals and of man—chiefly with reference to the sensory and sympathetic ganglia. Very little had been done in this field up to that time: most neurological research had been restricted to embryos or very young animals. But enormous changes take place as the organism matures. The subject had long invited investigation but until then no known method was adequate for undertaking it with any certainty of constant and reliable results. Here again the reduced silver triumphed. It could stain selectively the adult sensory and sympathetic ganglia even in material that was not freshly dead. Cajal's observations led to the unearthing of many now accepted facts regarding changes in the nervous structures with advancing age. In view of the importance of the modern science of geriatrics, the study of ageing—increasingly important because higher standards of living have raised the age at which men die—his findings are of significance today.

Studies of these and other changes in the nervous system opened the way for a renewal of interest in nervous pathology. Knowledge in this domain grew fast as fact after fact was brought to light. A whole school of neuropathology sprang up. Notable among its leaders were a number of investigators abroad, and in Spain Cajal's pupils Achúcarro, Lafont, and Castro. More than one hundred publications were fathered by Cajal's original paper pointing out some of the changes that occur in the nerves under the various stimuli of age and illness.

Cajal thought of his research on the ganglia as the most fruitful

Explorer of the Human Brain

of all his work during the decade from 1903 to 1913. It was in these years too that he undertook the study of developmental defects in the nervous structures, by no means uncommon in man, he raised the point that the eccentricities of certain persons may be due not so much to chance, heredity, or early conditioning, as to a failure of certain neurons to grow as they should. Because of this physiological failure, normal association paths may in these individuals be unusually weak or even entirely absent, resulting in peculiarities of attitude and behavior that have little or nothing to do with the training the person has undergone or the habit patterns he has more or less consciously built up throughout his life.

THE HELMHOLTZ MEDAL

ONE WINTRY DAY in 1905 a letter from the Minister of Foreign Affairs was handed to Cajal and with it an official-looking document from the German Embassy in Madrid. He read the letter and the document with growing astonishment. The Royal Academy of Science of Berlin, one of the eminent scientific bodies in the world, had awarded him the Helmholtz⁹ Medal. What could that be? he wondered. As he read further in the papers put so unexpectedly into his hands, he learned that this was a distinction bestowed every two years on the person who was thought to have made, within the interval, the most significant contribution in any field of human knowledge. The enormous medals, one in gold and the other a replica in copper, had before this been conferred upon such men as Virchow and Lord Kelvin. Modest Cajal asked himself how such an august society had ever come to think of him. He decided that his friend Waldeyer must have put in a good word for him. Within the next few weeks he was inundated by an avalanche of congratulations—a thing he was ever afterward to wince from. A

⁹ Hermann Ludwig Ferdinand von Helmholtz (1821-94) Eminent German physiologist.

message came from Alfonso XIII through his secretary Señor Merry del Val. A beautiful silver plaque was presented to Cajal by his students of the School of Medicine, this he gratefully hung in his office beside another he had received the year before from the Academy of Medicine and Pharmacy of Barcelona. After all the speech-making and banqueting had ended—weeks later—Cajal settled down to work again with a sigh of relief.

BETHE¹⁰ AND THE REVIVAL OF THE RETICULAR HYPOTHESIS

THE ZENITH of Cajal's career was reached in 1905 and 1906. In these years—a matter more important to him than his personal good fortune—he succeeded in finally establishing his neuron doctrine. It had not been easy. The doctrine had been fought from the beginning, and even after it had been widely accepted, it was constantly being challenged. Again and again the advocates of Gerlach's and Golgi's reticular hypothesis would resuscitate the concept of the Gargantuan spiderweb. Until the end of his life Cajal fought these outcroppings of the old, disproved theory, though they recurred with diminishing vigor as the years went on and the new doctrine took hold in the scientific world. A pitched battle was fought in 1906, from which Cajal emerged with banners high.

It had all started up again when certain investigators, aiming to refute the neuron theory, devoted their energies to the study of the way in which severed or injured nerves sometimes succeed in regenerating themselves, and of the stages by which the nervous system arises in the development of the embryo. For the most part, these investigators were young men eager to make a name for themselves. The leader and the most talented was Albrecht Bethe, whose arguments were so vigorous and persuasive that even such

¹⁰ For identification see note on page 172.

Explorer of the Human Brain

confirmed neuronists as Waldeyer and van Gehuchten were shaken in their faith

The strife became violent and abusive. The neuronists were forced to restate their case in self-defense. Cajal hated to waste his time in such futility. But his friends asked, "What are you thinking of? Why don't you speak?" And so at last he was driven to it. The time was not altogether wasted. He did refute his opponents thoroughly—at any rate, they were not heard from again for many years—and he picked up important new facts in the process of confirming his doctrine. Re-proving the proved by his new staining method of reduced silver nitrate, he was able to demonstrate beyond a doubt the same structures he had revealed in earlier years by the less reliable methods of Golgi and of Ehrlich. Very little remains of Bethe's theory as a general doctrine today.

NERVOUS REGENERATION

FROM NOW ON Cajal's chief scientific concern was the degeneration and regeneration of nerve cells. In this field he widened the horizons of neurology immeasurably. It had long been known that when a nerve trunk in a young mammal is cut, that part of the nerve that is beyond the place where the cut occurs degenerates and quickly dies.¹¹ What is left of its axon and myelin sheath is resorbed in the body. Yet some months later both the scar on the cut surface and the nerve fiber beyond the scar may show many newly formed fibers which at last may completely or partly re-establish the function of the injured nerve. How does this come about? There were two schools of thought. The first maintained that the newly formed fibers in the portion of the nerve trunk beyond the cut were merely prolongations, by means of the sprouting and growth of the axis cylinders, of the part of the trunk on the

¹¹ Augustus Waller, an English physician (1816-70), had demonstrated that a nerve fiber that has been severed from its nutritive center rapidly degenerates.

other side of the severed area. The other school declared that the newly formed fibers resulted from a differentiation and transformation of the old nerve fibers. By a regenerating process taking place in the body, they said, pieces of the old axon would be bound into a continuous thread and would finally be fused with the free axon of the severed nerve trunk.

For two years Cajal wrestled with this problem—operating on rabbits, cats and dogs. The report of his work was full of new data and contained striking pictures showing what actually took place. He found that within a few days after a nerve trunk is cut, the ends of the fibers in the central stump send out branches in all directions. Some of these grow through the scar, reaching the portion beyond the cut and extending through it to form the regenerated nerve. The others degenerate and are resorbed by the body. His findings, then, supported the views of the first school. The chief purpose of this study on the regeneration of nerves was to furnish objective proof that the newly formed fibers appearing on the far side of the cut nerve trunk represent buds or sproutings from the axons of the main trunk. Having accomplished his goal, Cajal turned to the detailed study of each separate step in the process. He found that the neurofibrils are composed of very tiny living units, which he called *neurobions*. These are able to grow and multiply almost independently within the protoplasm.¹²

¹² The modern view of nervous regeneration holds that it depends mainly on the chances provided for adequate numbers of the outgrowing fibers to establish connections resembling their original ones. Under favorable circumstances, very many nerve fibers sprout out from the central stump of an injured nerve and are met by many strands of Schwann cells reaching out across the scar ready to lend them to the nerve stump beyond it. The axon tips then progress down the nerve, many within each original tube. Some of them will connect with the appropriate end organ. When a sufficient number connect, the function of the injured nerve will be restored. (Schwann cells are the large, nucleated masses of protoplasm lining the inner surface of the sheath of Schwann, called the neurilemma, which is the thin membranous outer covering surrounding the myelin sheath of a nerve fiber or the axis cylinder of a nonmyelinated nerve fiber. See discussion on page 126.)

Explorer of the Human Brain

These discoveries led to a swing back to the neuron doctrine on the part of most of the outstanding scientists of the day. Van Gehuchten returned with the other prodigals. Cajal's pupil Tello strengthened his master's stand by the brilliant study he made of the regeneration of the motor end plates and the sensory nerve endings. Even Bethe showed himself conciliatory in the face of so much evidence brought to bear against his view. The new observations on nervous regeneration, then, gave added weight—and at a time when it was needed—to the whole neuron concept. Upon this once revolutionary doctrine modern neurology and psychology now rest as upon a solid rock, though throughout most of Cajal's lifetime the "rock" often seemed more like an all-engulfing quicksand.

10. *The Human Cerebrum Stammers Some of Its Secrets*

*... the surest key for unlocking the minds of others
was upon occasion and oftentimes either their tempers
and motives or their cerebral designs, and the more
we tried to penetrate equally by their tempers and
the more prudent and close by their designs.*

—FRANCIS BACON

EARLY one October morning in 1906, Cajal was awakened by the arrival of a telegram from Stockholm. "The Caroline Institute has awarded you the Nobel Prize in Physiology and Medicine," he read. This startling message was followed by a telegram of congratulation from the Swedish professor Retzius, and a few days later he received the official communication from the Royal Caroline Institute. From it he learned that he was to share his honor with Camillo Golgi, whose silver stain had brought such rich returns in Cajal's hands.

He was overwhelmed at winning the Nobel Prize, particularly since this was the first time it had ever been awarded to a histologist. The money involved was a tremendous sum to him—about \$23,000 at the rate of exchange of the time. This, one would think, would be welcome to a frugal professor with several children to support and ambitious experiments to finance, which, no matter how simply he managed them, were bound to cost more than he could afford. But the spontaneous pleasure he felt was at

Explorer of the Human Brain

once mixed with other feelings. He dreaded the flood of letters he would have to answer, the banquets, the speeches, the weeks of wasted time. He even thought of declining the award, of declaring it undeserved, for he felt that as a histologist he was not entitled to it. By the terms laid down in the ordinance of the Nobel Foundation, it seemed to him that the Section of Medicine and Physiology should rather confer it upon a pathologist, a physiologist, or a bacteriologist. But he was finally persuaded that one did not refuse the Nobel Prize.

Still, to keep the storm of congratulations from breaking over his head sooner than need be, he tried to hide the fact that the prize had been conferred upon him. It was no use. With crushing inevitability the press broadcast the news and the hated business began. To the mountains of telegrams, letters, and honorary diplomas, other things were added this time. Streets and cordials were named for him. He became the prey of the autograph hunters, of the seekers for petty sinecures. "There was some of everything," he said, "and at the same time both grateful for it and wishing it would stop, I had to resign myself to it with a smile on my lips and sadness in my heart." This went on for four months. His digestion groaned from the rich dinners given in his honor. His fingers itched to get back to his experiments. And all this in spite of his having long ago chosen as his field the most obscure and undramatic of the sciences!

Many of the tributes did touch him deeply, especially those from his students and colleagues, and perhaps most of all a gracious gesture from the physicians of Buenos Aires, who took up a subscription to finance the publication of one of his books. But, in the main, the celebrating was torture to him. To emerge from the excessive attentions visited on one on such occasions in Spain, he says, one must have a heart of steel, the skin of an elephant, and the stomach of a vulture.

Coupled with his dislike for notoriety was a gnawing fear. To be raised above the crowd is to invite the enmity of one's fellows

The Human Cerebrum Stammers Some of Its Secrets

His nature shrank from the hostility that his imagination pictured even before he had felt its biting edge

How, I asked myself, would my former rivals take my good fortune? What would all those scientists whose errors I had been unlucky enough to expose have to say about me? Considering all the investigators who had been so much more worthy of this honor than I, how could I justify the Institute's choice of me? And, looking toward Spain, how would I be able to appease the envy of certain professors—some of them from my own part of the country, who had always thought of me as a presumptuous mediocrity or a hard working fool? For the greatest enemies of the Spaniards are the Spaniards themselves

Events were to prove that his forebodings were not ill founded

The laws of the Nobel Foundation require that those receiving prizes attend in person the ceremony of formal bestowal, which takes place in Stockholm on the tenth of December, the anniversary of Alfred Nobel's death. Moreover, those who win prizes for scientific research must explain their discoveries in a public lecture. Cajal set out for Sweden in a reluctant and depressed mood. He arrived on the sixth of December and was at once introduced to his co-sharer in the prize for medicine, Golgi, and to the American statesman Theodore Roosevelt, who, ironically (or so it seemed to war-wrecked Spain), was being awarded the prize for peace. To Cajal, Roosevelt would always remain "the man of the most impetuously warlike temperament and the most out-and-out imperialist the United States has ever produced"

The king of Sweden, Oscar II, presided over the ceremony, which took place in the Royal Academy of Music. The whole royal family was there in full splendor, with the diplomatic corps, the descendants of the Nobel family, and a brilliant assemblage of scientists and men of letters. The medals and diplomas were presented individually by the king. The gold medal given to Cajal had on one side, in relief, the bust of Alfred Nobel and on the other an allegorical figure representing Medicine bringing comfort to

Explorer of the Human Brain

the suffering Below this figure Cajal's name was engraved The diploma too was a thing of beauty, designed by a Swedish artist

The lectures given by the laureates took place a few days later Cajal gave his on December 12 before a large audience He kept himself strictly to a simple exposition of the facts he had discovered and of the principles he had deduced from them As he always did when he was lecturing in a foreign land, he gave his discourse in French, calling it *Les structures et connexions des neurones* As usual, he illustrated his lecture with demonstrations of his preparations and with large colored wall charts He made a point of praising the work of his predecessor and present partner in the prize and he was sincere in his appreciation of Golgi's pioneering He knew that it had in large measure helped him realize his own accomplishments But Golgi, in his speech given the day before (also in French, *La doctrine du neurone—théorie et faits*), had had no kind words for Cajal Instead of reviewing and analyzing all the new facts that had been brought to light, he tried—vainly and a bit ridiculously—to resuscitate his half-dead network theory He did not allude even once to the many things that had been achieved in histology outside Italy or even in Italy since the remote date of his own work on the minute structure of the nervous system If one were to judge from his lecture, no forward steps had been taken since he had left the field—though, actually, immense progress had been made He made no effort, either, to correct any of his errors in the light of the newer knowledge, or even to admit them

Retzius, a noble and discreet man, was in consternation [said Cajal] and all the Swedish neurologists and histologists looked at Golgi stupefied I trembled with impatience as I saw that the most elementary respect for the conventions prevented me from offering a clear correction of so many mistakes and deliberate omissions What a cruel irony of fate to unite, like Siamese twins linked at the shoulders, adversaries of such differing natures!

But on the whole, Cagil's trip to Sweden was pleasant. He explored with keen interest the University of Upsala, the Stockholm Opera House, the floating rink, the harbor, and the fine zoological park. There was only one other discordant note besides Golgi's behavior, and that was due to the penuriousness with which Spain maintained its minister in Stockholm. While the dignitaries of the other large countries were housed in elegant mansions, the Spanish representative lived in a dingy tenement. He alone of all the foreign ministers did not give a banquet to honor the laureate from his land. Not that Cagil wanted another banquet—there had already been more than enough for his taste—but he deplored Spain's lack of prestige in Sweden as in all the other nations of the world.

ALFONSO XIII—THE EARLY YEARS

FOUR YEARS before Cagil's journey to Sweden, Alfonso, son of the Queen Regent María Cristina and posthumous child of the late king, had become ruler of Spain on his sixteenth birthday, May 17, 1902. Two days later he had solemnly promised to uphold the Constitution and its laws. Alfonso was a bright boy, spoiled, perhaps inevitably, and used to having his own way. Still he did have some realization of the responsibilities of his position and of the sterner duties of Christian kingship. The prestige of monarchy was immense in the Europe of 1902. Although Alfonso's powers were sharply limited by the Constitution, he was still free to rule in the grand style. And he did.

In 1905, he went to England to seek a bride. He soon met and fell in love with Princess Victoria-Eugénie, called Ena, who—as the niece of King Edward VII and daughter of the Princess Beatrice—was a granddaughter of Queen Victoria. Princess Beatrice had married the Prince of Battenberg (a title that during World War I was translated into Mountbatten). Even the rumor of a possible marriage between Ena and Alfonso stirred up an out-

Explorer of the Human Brain

burst of angry protest both in England and in Spain, for Ena was a Protestant and it was unthinkable that the queen of Spain should be anything but a Catholic. The princess, however, soon showed herself not averse to becoming one, and her godmother, the former Empress Eugénie of France, herself a Catholic, favored the union. So did King Edward, who liked Alfonso and was pleased with the thought of a closer bond with Spain. At this juncture Alfonso was warned that in Ena's heredity, as a descendant of Queen Victoria, there lurked a wasting illness—hemophilia, or spontaneous bleeding. She herself was not a "bleeder"—the actual malady commonly affects males only, but as a "carrier" she could transmit it to any sons she might have. Ena, however, was so lovely and radiant with health that it was hard for Alfonso to take the warning seriously.

All the arrangements were made for the wedding. On May 25, 1906, the princess arrived at the frontier of Spain, accompanied by her mother, her brothers, and her ladies-in-waiting. Escorted by Alfonso, they made a triumphant journey to the palace of El Pardo near Madrid, for Spanish tradition forbade a royal bride-to-be to enter the capital before her wedding day.

The marriage took place a few days later, on May 31. It was a sparkling spring day. The city blazed with the red and yellow banners of the Spanish Bourbons. Early in the morning the princess had driven with her mother in a closed car from El Pardo to the Ministry of the Marine to put on her wedding gown and veil. At 10:30 she emerged from the Ministry, followed by the Princess Beatrice and the Queen-Mother, María Cristina. The throngs that had been patiently waiting outside for hours for a glimpse of her shouted loud *vivas* as she stepped into the carriage that was to take her to the church. The marriage ceremony—a nuptial Mass and *Te Deum* in the Gothic church of San Jerónimo—lasted for three hours. After it was over, the procession started for the palace in the afternoon sunshine, cheering crowds lining the way.

There had been hints that an attack might be made on Alfonso

and Ena on their wedding day and many safeguards had been taken to protect them. All went well until the cortège had almost reached the palace. Suddenly, as the carriages were slowly making their way along the Calle Mayor, a huge bouquet of flowers was thrown straight at the royal coach from an upper window in a house near by. A bomb exploded when the bouquet hit the pavement, filling the air with smoke and chips of splintered wood. One of the white horses was killed and some of the others wounded, the rest tried to stampede but a groom held them in check. When the immediate danger was over, the young queen, pale and in tears, was helped into another carriage. Its curtains had been drawn to conceal her from the crowd, but Alfonso drew them back and the newly married pair rode on in full view of their people. Later in the day Alfonso went out unguarded to visit the homes of the persons who had been hurt or killed that day—more than a hundred had been injured and thirty-seven were dead.

Events later proved that the attack had been made by an anarchist from Cataluña, a young man of twenty-seven, named Morral. He had come to Madrid for this purpose a few days before the wedding and had taken a room in the pension at No. 88 Calle Mayor. On the evening of May 30, he was said to have returned to his rented room with a large bunch of flowers. As the wedding procession passed the house the next afternoon, he threw the bouquet with the bomb concealed in it from his window and then escaped from the house under cover of the confusion. When the Home Minister, Count Romanones, responsible for the safety of Alfonso and Ena, reached No. 88, he found eight dead bodies heaped up on the steps outside it. The inner staircase was stained with blood, and as he hurried up to the room from which the bomb had been thrown, he smelled the acrid explosive that had been used in it. (Two days later, Morral was captured and taken to the near-by village of Torrejón, where he succeeded in shooting the policeman guarding him and then fatally shot himself.)

Cajal was working quietly in his laboratory while these dra-

Explorer of the Human Brain

matic events were taking place in Madrid. For days the city seethed with excitement. But he pursued his research in his accustomed way, scarcely giving the screaming headlines a fleeting glance as he hurried along the Paseo de Atocha to or from his work. Though there must have been animated talk at the Suizo when he dropped in for the afternoon gatherings!

The beautiful English girl who had become their queen was popular with her Spanish people and she learned their language quickly. Her first son, the Prince of Asturias, was born eleven months after the marriage. Within the next seven years there was another son, two daughters, and two more sons. All four sons were afflicted in some way—three were victims of the hemophilia inherited from their mother and one was a deaf-mute.

Though Alfonso too was well liked in his youth, the early years of his reign were darkened by the conflicts of the various factions among his subjects who rebelled against the whole idea of monarchy (Cajal was with them in spirit, though he took no active part.) There were many threats against the king's life. There were constant changes in the government, constant struggles of Liberals against Conservatives, clericals against anticlericals. The progressive industrial North, led by Cataluña, with its chief city Barcelona, was continually at odds with the less advanced agricultural South. For a short time the Liberals seemed to be gaining ground. Don Segismundo Moret, a sincere Liberal and a friend and admirer of Cajal, became premier in the latter part of 1906. But he was soon succeeded by the Conservative Marquis de la Vega de Armijo, who in 1907 was followed by another Conservative, Don Antonio Maura.

Maura was a strong Catholic but he was not a clerical. He ruled as an enlightened despot and managed to bring order to Spain and to effect considerable reform in the corrupt practices by which the political "bosses" controlled local elections. He also put through some good labor laws and strengthened the police.

At this point Spain became embroiled in a disastrous war against

[222]

The Human Cerebrum Stammers Some of Its Secrets

the Berber tribesmen of the Riff Alfonso had been maneuvered into it by the politicians. Seeing the success of a similar French adventure in Morocco, the Spanish imperialists urged the king to try his hand at the popular game of snatching at empire. Spain did succeed in winning a zone of influence across the Strait of Gibraltar, an area about the size of the state of Massachusetts. This zone was backed by the mountain chain of the Riff. Native tribes lived in these mountains and from time to time they would swoop down upon the Spanish settlements, it was not long before troops had to be sent out from the homeland to protect the colonists. War broke out officially in July when Spanish workmen building a road from the town of Melilla to some mines in the hills were attacked by native warriors.

As he saw in the streets of Madrid groups of young soldiers about to be shipped out to the Riff war, Cajal must have felt again the leas of bitterness and futility his Cuban experience had left in him. Was there to be no end of this useless misery of overseas fighting? The Spanish people as a whole had little stomach for this war. The army too was already weary of it and sensed the venture to be the political juggling it was. Though the soldiers could not mutiny, the people could rebel. And soon laborers in the slums of Barcelona did stir up a revolt against it. By early August Barcelona was a storm center, all communication with Madrid cut off. The mob battled the police and sacked churches, convents, and monasteries for a week. At last the leader of the terrorism was captured. He was Don Francisco Ferrer, a man in his fifties, a militant atheist and founder of the confraternity of anarchists of which Morral had been a member. Ferrer was known throughout Europe as a freethinker, an advocate of free love, a strong adversary of clericalism, and founder of lay schools aimed at the educating of the illiterate masses of Spain. To a considerable degree, he was a true intellectual and an idealist with a sincere belief in the rightness of his mission. Upon his capture, he was promptly court-martialed and shot. His death caused a burst of indignation throughout the

Continent and he became a martyr in the eyes of his followers, inciting them to further revolts against the monarchy and all that it stood for

It was largely as a result of this Barcelona uprising that Prime Minister Maura lost his prestige with the people Moret made a furious attack upon him in the Cortes, accusing him of having sacrificed Ferrer to the clericals His government still further weakened by reverses in Morocco, Maura resigned in October, 1909

A new cabinet was formed under Moret, who sent General Weyler to Barcelona to keep order and released many political prisoners who had been captured during the terror—some of them Socialist or radical journalists Under the new law restraining the traditional corruption of local elections there was a strong trend toward the Left throughout all Spain In February, 1910, the Moret ministry resigned and was succeeded by the ministry of Canalejas

Don José Canalejas, like Maura before him, was a devout Catholic and at the same time an anticlerical Loving the Church, he deplored the machinations of those who tried to exploit it for their own self-interest He had been a strong Liberal, looking askance at the monarchy, until in time he had become convinced that the enthronement of Alfonso did express the will of the majority Then, too, Alfonso had started out as a Liberal and Canalejas believed the young king sincerely meant to establish a constitutional monarchy on the English model So he had thrown in his lot with Alfonso But Canalejas never wholly satisfied anyone The Liberals, who were more often than not anti-Catholic, railed against his Catholicism, while the Conservatives deplored his liberalism and his anticlericalism And as the king's youthful liberalism waned, he too found Canalejas troublesome, for the minister interfered with the full exercise of the royal prerogatives, which were now looming large in Alfonso's disillusioned eyes

The Human Cerebrum Stammers Some of Its Secrets

In their struggle against the growing power of the aristocrats, the clergy, and the army, as well as the growing conservatism of the king, the Liberals accused Prime Minister Canalejas of betraying their cause in allowing Alfonso to come to a secret understanding with the Church. He defended himself vigorously against this charge in a letter to his friend, the republican novelist Pérez Galdós.¹ But his prestige was waning and no amount of explaining could restore it. On November 12, 1912, while walking to the Home Ministry, he stopped to look at some books displayed in a bookstall at the spot where the Calle de Carretas runs into the Puerto del Sol. A man in a dark-blue suit and a dark overcoat stole up behind him and shot him twice, wounding him in the temple and behind the ear. He was rescued by some people near by and taken into the Ministry, where he died a few minutes later. The assassin proved to be one Párdinas, a native of Aragon, who had been appointed by a group of anarchists to shoot the Prime Minister. With the death of Canalejas, Alfonso lost one of his sanest and most disinterested advisers. Henceforth he would pursue to the end his mistaken policy of increasingly reactionary rule. Count Romanones was put in Canalejas' post. He was succeeded for a short period by Dato and later restored to office a second time.

CAJAL AS EDUCATOR

WHEN CAJAL had returned from Stockholm in 1906, Don Segismundo Moret, then Premier, had urged him to accept the post of Minister of Public Instruction. Cajal did not feel himself to have the qualifications that make a politician and had no liking for the role. But a long train of events led to his final acceptance.

Don Segismundo was determined to bring about reforms in the

¹ Benito Pérez Galdós (1845-1920). One of the foremost novelists of his time, noted for his historical fiction and his romances of everyday life in Spain.

Constitution and to introduce laws more truly democratic than any ever written on the Spanish statute books. He made it clear to Cajal that his co-operation was a patriotic duty, pointing out—a fact Cajal well knew—that the educational system in Spain needed revamping from top to bottom. Cajal was stirred by his urging and made some practical suggestions for changes in the university curriculum. He recommended that eminent professors from other countries be engaged for a few years, that brilliant students be sent at government expense to attend international scientific conferences to meet foreign investigators, that industrial colleges be established for those with special skills along the lines of commerce and industry, that health and character-building be fostered among university students as was done in England, and that an institute for advanced research be founded in which professors in the Spanish universities might have at their command the facilities and equipment they needed to carry on their original work. Don Segismundo agreed with these ideas completely, and was now more eager than ever to have his help. At last Cajal hesitantly agreed.

While attending the International Medical Congress at Rome, away from Moret's persuasiveness, Cajal thought the whole matter over and decided that it was not for him. He wrote a letter to Don Segismundo telling him so. Moret was angry at him for changing his mind, but he forgave him—after he had succeeded in making him change it back again. Don Segismundo's own position was always precarious, however, and in a few months his ministry fell without having attained any of the goals he had set for it.

But Cajal was destined to be an educational reformer all his life. He collaborated in the formation of the Committee for Widening the Scope of Education (*Junta para Ampliación de Estudios*) and was its president for many years. He saw clearly the imperative need to put Spanish youth in contact with the source of scientific creativeness in other lands. Through this realization and through

his efforts to attain his goal, he influenced education at many points. In the quality of his influence as also in his personality as a teacher he resembled Giner de los Ríos, deán of Spanish educational reformers, and Menéndez Pidal,² eminent Spanish critic and man of letters.

As the years passed, Cayul's proposed reforms were adopted in the Spanish universities to a considerable extent. From the experiences of his own boyhood, he had developed a strong detaste for the system by which Spanish students were forced to swallow large doses of theoretical data and empty formulae without comprehending their real meaning or their application to life. To discover truth, Cayul was convinced, one must not turn the mind inward on itself but outward to objective reality. "The most brilliant discoveries," he wrote, "have been due not to a knowledge of written logic but to that living logic that man possesses in his spirit, by which he elaborates ideas as unconsciously as Jourdain³ spoke prose. . . . Men of genius do not bow to written rule; they prefer to make them. As Condorcet⁴ says, 'The mediocre can be educated, but genius educates itself.'"

In harmony with this way of thinking in his book of advice to young researchers, *Reglos y consejos*, Cayul directs his suggestions to the will rather than to the intellect. The will alone can be educated, he declared, and every masterpiece in art or science is born of a great desire on the part of its creator. "Boldness tries its strength and conquers or is conquered, but excessive modesty avoids the battle and condemns itself to shameful inaction."

² Ramón Menéndez Pidal (born 1869) Statesman, critic, educator, editor, man of letters. Professor of Romance Philology at University of Madrid. Member of the Junta para Ampliación de Estudios. Lectured at Johns Hopkins University and at various South American educational institutions. In 1913 was named Counselor of Public Instruction in Spain.

³ Monsieur Jourdain, leading character in Molière's comedy *Le bourgeois gentilhomme*. On hearing "prose" defined by his literature teacher, he was amazed to realize that he had been speaking prose all his life.

⁴ The Marquis de Condorcet (1743-94) French metaphysician.

Explorer of the Human Brain

More concretely, in giving advice to young scientists, he urges them first to know well all the relevant literature to date. Once this is mastered, they should strive to make their own observations as objective as possible, yet realizing that they can never be entirely so. Certain emotional colorings are bound to enter into them. Though these must be held firmly in check, they should not be crushed utterly—they have their value. Emotions—enthusiasm, keen interest, the will to succeed—light up the cerebral machine and give it the heat it needs to become the forge where fortunate intuitions may be molded into theories.

Though his faith in the transforming power of education never waned, Cajal's natural impetuosity was tempered with the years. His friend Dr. Martínez Vargas tells that once during the dictatorship a decree was published that was thought to be detrimental to the rights and the dignity of the Committee for Widening the Scope of Education, and the Committee wanted to resign in a body as a gesture of protest. But Cajal firmly and quietly dissuaded the members from doing this—it would mean the sacrifice of the work of many years. Spanish education was worth more than their hurt pride.

BATTLES WITH DRS. HELD AND APATHY

CAJAL had feared the envy and hostility that his winning of the Nobel Prize would incur. He had already had a taste of these in his contact with Golgi at Stockholm. It was not long before his presentiments were justified again. In 1907, a man who had been his friend, had even translated one of his books, Dr. H. Held of Leipzig, showed his antagonism in an article presenting his criticism of Cajal's defense of his neuron doctrine. In 1907, too, Dr. S. Apathy, a Hungarian naturalist and scholar, expressed his anger at certain objections Cajal had made to a paper of his on the continuity of the neurofibrils in worms. Yet Cajal had raised these

objections four years earlier, and Apathy had never openly expressed his resentment before.

Though stunned by these attacks, Cajal kept his hot temper in check. In answering his opponents, he carefully worded any personal remarks and confined himself strictly to a sane, reasoned, tactfully worded defense of the scientific stand he had taken. His refutation of Held's position has been confirmed by the findings of later years. As for the violent Apathy, who wrote a sheaf of denunciatory books and papers about Cajal's observations and theories, after Cajal's answer he was not heard from again. Whether this was due to pique or to inability to put forth any more arguments, it is impossible to say. Cajal was charitable enough to interpret his silence as contrition. Another battle had been fought and won for the neuron doctrine. But even in the glow of victory Cajal knew that this battle was not to be the last.

A FRUITFUL DECADE

THE YEARS from 1907 to 1914 passed quickly. They were years of vigorous investigation and discovery. Far from resting on his laurels, Cajal was determined to earn new ones. Much of his autobiography was written in this period.⁶ Also he completed a number of monographs on various aspects of the comparative and pathological anatomy of the nervous system. This work was chiefly concerned with the cerebellum, the medulla oblongata, the acoustic ganglia, and the sensory and motor neurons.

His principal achievement, however, was an exhaustive study of the processes of degeneration and regeneration of the neurons and the axons of the ganglia, the cerebellum, the cerebral hemispheres, and the spinal cord. His findings fully confirmed the neurotropic hypothesis he had formulated as early as 1892. His

⁶ A new edition was published in 1923.

investigations were carried further by Dr Francisco Tello,⁶ working closely with Cajal. The immense mass of data their experiments garnered definitely refuted for all time the then current belief that the central nerve tracts cannot ever be regenerated. The fruits of their research were collected into two large volumes, *Estudios sobre la degeneración y la regeneración del sistema nervioso* (Studies on the Degeneration and the Regeneration of the Nervous System). The publication of this now classic work was paid for by the physicians of the Argentine Republic, who prepared for it a foreword expressing the high estimate they placed on Cajal's contributions to neurology. This work was one of the crowning achievements of his career. It was reissued by the Oxford University Press in English translation in 1928.

During these same years Cajal worked on new methods of preparing his materials for study—new stains and new techniques that would yield more indisputable and more universally reliable results. The perfecting of such procedures is a formidable task, exacting unending patience and scrupulous care.

Oh, the feverish and impatient hours [he writes] in which one anxiously awaits the fortunate reaction which flirts without surrendering! The most serious thing about work of this kind is that whole years may be consumed in it without one's discovering anything worth while. And the disappointment when the chance discovery of interesting reactions cannot be repeated even after persistent effort and endless trial and error!

It had been by just such a fortunate accident that in 1892, while examining pieces of the brain of a young rabbit stained by a mix-

⁶ In 1931 Dr Francisco Tello published a report of certain experiments of his in which fragments of peripheral nerve were implanted in the brain. The results seemed to demonstrate that the neurons of the central nervous system can regenerate themselves, just as peripheral nerves often do, and that this regenerative process is stimulated by neurotropic substances produced in degenerating nerves—thus furnishing added experimental support to Cajal's neurotropic theory.

Explorer of the Human Brain

him and disclosing facts about its embryonic development and its behavior in the process of degeneration and of regeneration

Aided by his pupil Achúcarro, Cajal invented still another stain, using gold sublimate, a simple procedure by which the neuroglia of the cerebral cortex can be impregnated with a violet color. The use of this method proved invaluable in permitting the study of the pathological changes in the human glia in paralytic and senile dementia (work carried on by Achúcarro) and of the softening of the brain (studied still further by another pupil, Pío del Río Hortega)

As a change from the more serious work done in these years, Cajal reverted to the artistic leanings of his boyhood with the preparation and publication of a book on color photography, giving an analysis of the scientific principles underlying it. He had not undertaken this work solely for his own pleasure. It was also to help his eldest son, Santiago, to find a suitable career to which to devote his life. This young man, the one of all Cajal's children who most resembled his father both in looks and in temperament, had contracted a serious heart ailment early in his boyhood. He was not strong enough to enter one of the learned professions, so his father set him up as a bookseller, chiefly to give him something to do and to uproot his deep feeling that he was unable to cope with normal living. The book on color photography was to stimulate his efforts as an editor and to provide the start for future undertakings of a similar kind. But Santiago died in 1911,⁷ at twenty-nine years of age, before his father's plans had reached fruition, and Cajal had to be both author and editor.

⁷ Cajal's second son, Jorge, is also dead. His death occurred in 1937, three years after his father's. He was a physician and bacteriologist, member of the Institute of Hygiene of Alfonso XII. He was married to Doña María Conejero. The youngest son, Don Luis, also became a doctor. Cajal's three daughters, Fé, Paula, and Pilar, are still living in Spain. Doña Fé married Dr. Tomás Pérez de Tudela, a physician. Doña Paula also married a medical man, Dr. Angel Canadés. Doña Pilar married an artist, Don José Padró. Cajal had several grandchildren before he died in 1934.

The Human Cerebrum Stammers Some of Its Secrets

Another detour from the path of pure scientific writing was Cajal's *Cuentos de vacaciones* (Holiday Tales), also written in this period. These were popularized science stories by "Dr Bacteria," the nom de plume under which Cajal had published several pseudo-scientific writings in his youth. He did not offer this book for sale but merely gave copies of it to a few of his friends, hoping that some day he might have a chance to remedy its defects and to get it out in a proper edition.

LATER YEARS OF ALFONSO'S REIGN

WHEN WORLD WAR I burst upon Europe with startling suddenness in 1914, Spain was enjoying a period of progress unprecedented in many years. Alfonso had at last succeeded in consolidating warring factions to the greater material prosperity of the whole nation. It had not been easy and the Liberals were still far from content.

When the war began, both sides tried to win over Spain. The people were divided. The working classes, the tradesmen and industrialists, and most of the intellectuals were for the Allies, the clergy, the army, and the aristocracy were pro-German. All agreed on one point, however. Spain had no stake in the war and should stay out of it. The ministry of Count Romanones was frankly Liberal and pro-Ally. But Spain's neutrality was proving to be profitable. There was full employment in filling the war orders that flowed in, and great wealth from foreign shipping. As the profits from shipping grew, so too did the number of torpedoings of Spanish vessels by German submarines off the coasts of Europe. By 1916 Spain had lost 30,000 tons to the U-boats and probably 50,000 more as an indirect result of submarine warfare. When Germany tried to blockade the Allied coasts, Count Romanones sent the Kaiser a stern note denouncing this policy. But, realizing that sternness availed nothing unless his people were ready to

fight, he resigned his office, since he knew that public opinion would not back him up to that extent in his pro-Ally leanings. He lost the leadership of his party and was followed by a ministry determined to preserve Spain's neutrality at any cost.

The situation was complicated still further by a revolutionary movement that began in the army about 1916, resulting in the forming of the so-called committees of defense. These self-appointed committees interfered with the Government and, although they were stoutly resisted, the Government soon showed itself powerless to suppress them. The success of the committees stimulated other revolutionary groups to assert their power. Soon all Spain was in a ferment of rebellion, demanding radical changes in government and reforms in the Constitution. On August 13, 1916, a general strike paralyzed the whole country. A state of war was declared. This revolt was eventually put down by the army, thus proving the military committees of defense to be the sole strong force in Spain.

The Allied victory in 1918 brought an upsurge of democratic feeling, particularly in Barcelona, where strife again broke out between the army and the civil authorities. The government then in power resigned, and the Conservative leader, Don Antonio Maura, took office on April 15. Shortly afterward, Maura asked Alfonso for a decree to dissolve the Cortes. To the dismay of all parties, this was obtained, it amounted to a practical coup d'état on the king's part. But Maura's government fell soon after—on July 20. It was followed by other precarious governments equally ineffectual. The whole trend of the period showed the disintegration of the system of two political parties which had been instituted years ago by Cánovas and Sagasta and had up to now served the king in good stead in giving a semblance of true constitutional government on the English model. The rapid deterioration of the old system was due to three main causes: its own internal weakness, attacks from warring factions—Socialists, radicals, Catalan home-rulers, and

The Human Cerebrum Stammers Some of Its Secrets

the new military committees, which had in effect taken over what political power was left.

The war had brought wealth to the Spanish middle classes. Votes were now harder to buy. The machine *políticos* could not now control elections as surely as they had once done. In an effort to cope with this state of affairs Alfonso swerved openly to absolute rule as far as he could manage it. In this he was backed by a large number of his subjects, who had grown impatient with the meaningless show of a parliamentarism with nothing of the substance of true democracy in it. Underneath a seeming complacency were insurgent cross currents, seething intrigues, and an abortive movement for the independence of Cataluña.

SPANISH HISTOLOGY IN THE WAR AND EARLY POSTWAR YEARS

IN THE midst of this political and social welter, Cajal and his assistants worked doggedly day after day in the Laboratory of Biological Investigation. The war years had brought only sorrow to Cajal. His health had failed. His old zest was gone. Continuance of his work was made more than ever difficult by the fact that for six years now he had been cut off from the scientists of other lands and thus from the main current of scientific thought in the world. Not that much was being done in pure histological research anywhere in these years. Inevitably the war had focused attention on the more immediately practical aspects of scientific study—finding new ways by which broken bodies might be patched up quickly, and at the same time devising new methods of destruction.

A few important discoveries were made by Cajal and his co-workers by sheer perseverance, lacking the old fire. To the paralyzing mood of futility was added another handicap. The cost of scientific instruments and reagents imported from abroad had

doubled and the difficulties of obtaining them had multiplied as the war went on. The price of printing, paper, and engraving soared almost beyond the modest means of Cajal's laboratory.

When the war was over and communication with the outside world was re-established, Cajal learned with sadness that most of the foreign scientists who had been his friends, men interested in his work and able to evaluate it, were dead. Van Gehuchten had died an exile in England, his fine library and his collection of specimens burned in the destruction of the University of Louvain. Waldeyer, Ehrlich, Retzius, Edinger, and Krause were dead too. Happily, America still held a few men who knew Cajal's work and could follow along the course he had charted. Most of the remaining scientists did not know Spanish, and for years after the war Cajal was to have the disconcerting experience of seeing men of other nations announce as their own, discoveries that had been made fifteen or twenty years earlier in Spain.

He came to realize more keenly than ever before the imperative need of having his own and his co-workers' writings promptly translated into the better-known languages of Europe. Immediately after the end of the war he set about having the most important of his already published works translated into German, English, and French. He now saw that he had made two great tactical errors in the early years of his scientific productivity, errors that had contributed a great deal to the general ignorance of his achievements. First, he had too often failed to have his material translated, in a mistaken belief that a knowledge of French and Italian, quite common among the scientists of the time, would enable them to cope adequately with Spanish. And second, he had included accounts of his most important findings in large volumes which, when published, proved too expensive to command a sale large enough to give them the wide circulation they should have had even among investigators in his field.

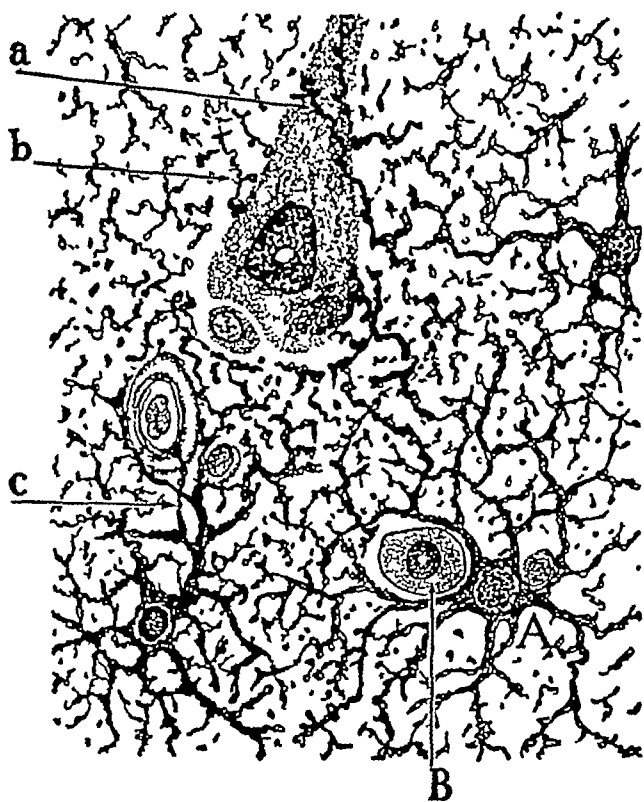


FIG 9 —PROTOPLASMIC NEUROGLIA OF THE CEREBRAL CORTEX OF A NORMAL ADULT MAN (Stained by Cajal's gold-sublimate method) A, protoplasmic astrocyte, B, neuron with short axon, a, b, pericellular pedicles with neuroglial appendages, c, fine perivascular pedicle (Courtesy of Dr Francisco Tello, Director, Instituto Cajal, Madrid)

In 1918, for the first time, Cajal succeeded in photographing the neurofibrils within the neurons. He also outlined a method of procuring colored transparencies of these threadlike structures for projection on a screen. It was in this same year that Dr Pío del Río Hortega, working in Cajal's Laboratory of Biological Research, differentiated two types of cell in what Cajal had labeled the "third

element"⁸ of the nervous system. He found that these cells differed from each other in origin, structure, and physiological features and gave them the names *microglia* and *oligodendroglia*. He could not have made this differentiation without the use of the silver-carbonate stain that he had invented some time before. Through it, he discovered all the essential facts known today about these cells.

In his unpublished memoir⁹ which he called *El maestro y yo* (The Master and I) Río Hortega tells the story of his discovery and

⁸ *Neuroglia* or *glia*—connective or supportive element of the nervous system as contrasted with the true nerve cells, the *neurons*. The neurons and the neuroglia were the two known elements of the nervous system, the hitherto undifferentiated microglia and oligodendroglia constituted Cajal's so-called "third element."

The investigations of recent years have added considerable information about the exact relationships of the interstitial tissues of the central nervous system to one another, largely through the use of the silver stains invented in the laboratory of Ramón y Cajal. Four forms of glia are now recognized: ependyma, macroglia, oligodendroglia, and microglia. The ependyma make up the lining membrane of the ventricles and of the central canal of the spinal cord. The macroglia provide the principal interstitial tissue for the support of the neurons; they have processes going to the blood vessels and may have a nutritive function. The oligodendroglia are small neuroglial cells with few dendrites; they are found in great numbers in the white matter, arranged in rows, and in the gray matter, where they are often grouped near blood vessels or about nerve cells as satellites. Microglia are small cells with spiny processes, found scattered through the central nervous system. Macroglial cells are important in the repair of injured nerve tissue; sometimes they multiply beyond need and form a tumorlike growth called a glioma. It is now believed that the oligodendroglia deposit myelin around the axons early in life. They may play a part in the repair of axons stripped of their myelin as a result of injury or illness. They may also act as phagocytes and carry away degenerated myelin. The microglia appear to be scavenger cells; they are found near every degenerative brain lesion. Some authorities believe the oligodendroglia are scavengers too, especially in the white matter of the spinal cord where the microglia are scarce.

⁹ Material generously supplied to the author by Dr. Moisés Polak, Director of the Laboratory of Histological and Histopathological Research of Buenos Aires, an institution founded by Dr. Pío del Río Hortega, who became its first director. Translated from the Spanish.

The Human Cerebrum Stammers Some of Its Secrets

describes the personal dilemma in which he found himself while he was making it

As soon as it was devised [i.e., the silver-carbonate stain] I seemed to sense a certain suspiciousness toward me. Perhaps I only imagined it. In any case, I paid little attention to it, absorbed as I was in my work. I was beginning to glimpse something of possible importance, and I was at the same time encouraged and dismayed by it, for I was sure that what I was about to find would not conform with what the master had disclosed on a subject he had wrestled with only a few years before and thought he had definitely settled. Through the use of his selective stain, Cajal had revealed in the interstitial warp and woof of the nervous tissues, in addition to the well-known neuroglia, elements that had no cytoplasmic prolongations. These he called "corpuscles without processes" or the "third element."

I was beginning to doubt the accuracy of this concept. Without question, there are cells differing from the classic neuroglia, but they do not lack processes, as Cajal had supposed. He had gone astray because he had assumed that his technique would show the ramifications of the neuroglia with absolute certainty, and he denied their existence when they were not visible. Nevertheless, every day I found evidence that the supposed "corpuscles without processes" *did* have prolongations. But if I should succeed in proving that they did, I should have to make a new interpretation, rectifying the master's idea in part. Would he thank me for that? I was afraid he would not, seeing that he was quite attached to his view about the third element and some scientists abroad had already accepted it.

If Achúcarro had been at the laboratory, Río Hortega would have confided his problem to him, but Achúcarro, stricken with tuberculosis, was slowly dying at his home after a useless rest cure in the Guadarrama Mountains. So he said nothing to anyone at first. His researches progressed with uninterrupted success. He already had enough facts to establish a hypothesis and should soon publish his findings if he wished to claim priority, for now that he had made known the special method he had devised and used, others would be sure to make the same discoveries shortly. But

months went by while he was torn between the conflicting emotions of personal loyalty to Don Santiago and the natural desire to have his own work known and valued. Cajal seemed to him to show scant interest in his investigations on the "third element" and never encouraged him to publish what he had found. But Río Hortega did write his report at last.

After a year of hesitation, I made sketches, edited my paper, and one day risked showing it to the master, reading my conclusions aloud to him. I remember the day very well. We were standing together in the library. He listened attentively and when I had finished reading, he made this observation: "I think your assertions are too daring. They will arouse a great deal of controversy." "I know that, Don Santiago," I replied, "but I am so sure of what I have found that, no matter how silent I keep now through too much prudence, others will surely point out the same things very soon, for they are too evident to be overlooked much longer now that there is a method by which to demonstrate them."

Río Hortega did finally publish his observations and, as Cajal had predicted, they did cause controversy. The dispute finally ended in the confirmation of Río Hortega's discoveries, though Cajal took no part in it, and in his autobiography he attributes the discovery of the microglia to Achúcarro, saying that Río Hortega's contribution was the detailed study he made of these cells in the brain tissue. But Achúcarro never claimed to have discovered the microglia. Río Hortega both discovered them and studied them, and not in the brain alone, but throughout the entire nervous system.¹⁰

Why Cajal should have been unjust to a follower whom he seems to regard so highly whenever he mentions him in his writings, it would be difficult to say. Could it have been because of the rigidity of old age, which made it impossible even for this fair-

¹⁰ Evidence for this view is presented by Dr. Moïses Polak in his *Pío del Río Hortega (1882-1945)*, publication of the *Archivos de histología normal y patológica*, Buenos Aires, Vol. 3, September, 1947.

mined and kindly man to evaluate the younger man's work at its proper worth? Perhaps. Perhaps, too, a more open and straightforward approach to him on Rio Hortega's part, if he had been able to make it—an approach with more confidence in it and less assumption in advance that Cajal would be hostile—might have made Don Santiago more ready to accept the new facts rectifying what he himself had thought. Or perhaps he quite honestly did not think Rio Hortega had proved his thesis sufficiently well at the time they discussed it to convince him that it was unassailable. He may have made a wholly unintended mistake when he attributed Rio Hortega's discovery to Achúcarro, who was dying when it was made—a mistake due to a slip of memory, to advancing years. In any case, to be unreceptive to the honest proof of a well-founded hypothesis offered by one of his students was the last thing Cajal would have wished.

During the postwar years Cajal made detailed investigations on a subject perennially fascinating to him—the retina and the optic center of insects. In this research he was aided by his assistant, Don Domingo Sánchez. In his study of the retina and the optic mechanism, with its ingenious adaptation of means to end, Cajal felt his faith in Darwinism shaken for the first time. Here he sensed more clearly than in any previous investigation he had made what he calls "the shuddering sensation of the unfathomable mystery of life." He was intrigued by the elaborateness and the efficiency of the insect eye. "Compared with the retina of these comparatively humble representatives of life, the retina of birds and of the higher mammals seems coarse, crude, and elementary," he wrote. "The comparison of a rude wall clock with an exquisite tiny watch would give the idea, the eye of the insect not only consists of more delicate mechanisms but combines, besides, highly complicated organs not represented in the vertebrates at all."

His next publication dealt with the small simple eyes that insects possess in addition to their large compound eyes. He tried to formulate a reasonable hypothesis as to why insects have such eyes,

Explorer of the Human Brain

what biological function they serve. He came to the conclusion that the compound eyes are the instrument by which the insect perceives color and sees during the day, and that the simple additional eyes have to do with the perception of vague, uncolored impressions, and hence are chiefly adapted to night vision. He also made further investigations on the cells with short axons in the fetus of the mouse—investigations completed and perfected later by Doctor Tello. The chief product of this work in 1919 was a study on the development of the sensory nerve endings, and in 1920, a study on the sensory apparatus of ants.

THE MASTER AND HIS SCHOOL

DR FERNANDO DE CASTRO, a leader in Spanish science today, gives this picture of Cajal and of his teaching during the war years and the years immediately following ¹¹

I came to know Cajal in 1914 during my first year in the medical course. He taught histology. His students were awed by this encounter with a man who was recognized as a leading scientific figure. Cajal's vigorous voice helped to make the dry subject he taught an interesting and pleasant one, and his teaching was at the same time remarkably profound and lucid.

He had the romantic air of the professors of the time. He used to go about wrapped in a voluminous Spanish cloak, just as Joaquín Sorolla ¹² pictured him in his portrait.

It was not usual to have projectors in the classroom in those days. Cajal made up for this great lack by accompanying his explanations with marvelous drawings on the blackboard, all of them revealing his extraordinary talent as an artist.

Usually he devoted the first quarter-hour of the class period to asking the students questions on the material that had already been pre-

¹¹ Translated from the Spanish. From a personal communication to the author.

¹² Joaquín Sorolla y Bastida (1863-1923) Spanish painter.

The Human Circulation Discovers Some of Its Secrets

sented. The pupil who was to give the answer would go down from the benches in the lecture hall, walk to the desk in the center, and sit down facing the lecturer, completely isolated from all his companions.

Any answer was admitted if it contained a grain of verisimilitude. One day I was asked to talk on the origin of the blood platelet. I had not been able to study anything about the subject and had heard no lecture on it. Nevertheless, I put up a bluff and elaborated a fantastic theory, though not a totally impossible one. When I was through Cajal said: "That would be fine if it had been discovered, but the origin of the blood platelet is not yet known."

He never interfered with the private concerns of his student. He even allowed them to do the experiments in his class if they did not disturb others. But when that happened he would become noticeably irritated. One day when he was explaining the anatomy of the retina, he observed two students of opposite sexes flirting with each other. He continued his lecture equably. In concluding it, he said: "It is established that visual acuity is greater in the central fovea than in the rest of the eye, all that does not keep one from seeing what is reflected at the periphery, such things as I am occupying now. Students, please be quieter, pay attention, and do not disturb your classmates."

Every day he went to the Faculty of Medicine to give his lecture, and every day he would pay a visit to the histology laboratory to keep an eye on the work being done by his assistants and his advanced students.

From seven in the morning until ten he would write in bed. A little while before going to the School of Medicine he would prepare his lecture on histology or pathological anatomy, which he would give until twelve. He would spend the whole afternoon working in the old Laboratory of Biological Research, of which he was director. In the evening, sometimes as late as midnight, he would be seen leaving the building on the Paseo de Atocha to go home.

In later years Cajal never forgot his role as teacher, though less and less, as he grew older, was he required to do teaching of the more formal kind. But he was always a guiding spirit in the laboratory, orienting young minds along the lines he had marked out in his own youth and early maturity. That he felt this to be one of the

Explorer of the Human Brain

most rewarding and enduring parts of his contribution to science and to his country is everywhere clear. Long ago in his book of advice to researchers, *Reglos y consejos*, he had stressed the importance of training disciples to carry on one's work.

It is essential for the cultivator of science to work for his own spiritual multiplication. In this way the life of the teacher is made full and fertile since it carries potential new beings within it. The task is wearisome, to be sure. The activity of the professor branches off into two parallel paths: that of the laboratory and that of the classroom. Thus his troubles are multiplied but his returns are increased in proportion. Besides gaining new ideas of his own, he enjoys the pleasure of mental fatherhood and finds his reward in fulfilling the threefold mission of teacher, investigator, and patriot. He will not spend his declining years in a sad solitude but will approach his end surrounded by a throng of loving pupils capable of understanding what he has done and of making it fruitful and lasting.

This picture of an old age rich in dignity and in the respect of one's followers describes Cajal's own last years. He had the satisfaction of seeing a school of Spanish histologists come into being, largely through his endeavors, and of knowing that it would outlast him and be an earnest of the revival of science in Spain. One of his students, the neuropsychiatrist Nicolás Achúcarro, the brilliant teacher who died of tuberculosis in 1918 before his great promise had been fully realized, devoted his attention to the neuroglia, chiefly, and developed a new stain for connective tissue. The discovery of the microglia and the oligodendroglia by his follower, Pío del Río Hortega, constituted an important contribution to nervous anatomy.

Perhaps the most outstanding of all Cajal's students was Dr. Francisco Tello, who succeeded Cajal both in the chair of histology at the University of Madrid and as director of the laboratory established after Cajal's retirement and named in his honor. Dr. Tello is known for his investigations on the neurofibrils, on the transplantation of cerebral nerves, and on the development and

The Human Cerebrum Stammers Some of Its Secrets

regeneration of nerve endings. Among the younger men—some of them pupils of Cajal's pupils—were Fernando de Castro, who investigated the neuroglia and the sympathetic ganglia, Villaverde, who made contributions to neuropathology, Sánchez, whose field was comparative neurohistology, and Lorente de Nó, who did research on the auditory and vestibular nerves. All these men, and others whose work they directed, were to gather facts of significance, correcting or filling out details in Cajal's work and thereby increasing the sum of histological knowledge the Spanish school gave to the world.

Cajal never looked upon the achievements of his students as in any sense of his own making. Many of them perfected their training outside Spain. But it was to these men that he confided his thoughts and the flashes of creative insight that led to new discoveries. His chief function, he felt, was to stir up enthusiasm and courage when weariness or adversity had made them burn low. He once wrote:

When the dark sea looks tranquil at night, a mere stirring of the water is enough to make clouds of shining noctiluca kindle their light and gleam like stars. The same thing happens in the ocean of society. One need only shake the thicket of sleeping neurons, make them vibrate with the excitement of novelty, and inspire them with noble restlessness.

It was enough for two or three of us—one the great Dr. Simarro—to jolt the drowsiness of our young men, for a whole constellation of worthy investigators to rise in our midst. Without being overoptimistic, I am convinced that in those fields of study that require ingenuity, patience, and perseverance, the Spaniards will show themselves to be the equal of the men of the North. One need only awaken their scientific curiosity, which has slept through four centuries of mental slavery, and kindle in them the sacred fire of personal inquiry. In our country, scientific genius is not yet conscious of itself. It is the teacher's duty to reveal and guide it.

In reading this, one cannot help recalling the dark figure of a young soldier on his way out to Cuba so many years before, looking,

Explorer of the Human Brain

fascinated, from the deck of the *España* at the swarms of phosphorescent noctilucas, seen now for the first time, shimmering against the blackness of the Atlantic

This is his own apologia

I have aimed that my life should be, as far as possible, a living poem of intense action and of secret heroism in the cause of science. My work is slight but it has been as vigorous and original as my slender talents permitted it to be To judge it with some knowledge of the conditions surrounding it, one must remember what Spanish histology was like in 1880 when I made my timid beginnings and what it is like today I do not wish to overlook the invaluable collaboration of others, but I believe that I can truthfully say that my obstinate work has had a part in the renascence of histology in Spain in our day As time goes on, my insignificant personality will be forgotten and with it, no doubt, many of my ideas will die Nothing can escape the inexorable law of life The facts first associated with the name of one man end by becoming anonymous, lost forever in the ocean of universal science The hot sun of the present is followed by the cool moonlight of the history of learning

But let us drive away melancholy thoughts, mother of inaction Let us devote ourselves to life, which is energy, renewal, progress And let us keep on working Only tenacious activity on behalf of truth justifies living and gives us consolation for all the suffering and injustice of life Only this possesses the power to convert the obscure social parasite into the legendary hero

Let us then cultivate our garden, as Voltaire used to say, fulfilling as far as we can the twofold duty of men and patriots For the biologist the supreme goal is the solving of the formidable enigma of all living things surrounding us No matter that our work must be premature and incomplete Meanwhile, until the millennium dawns, we shall have made the world a pleasanter place for man

II. Retirement and Last Years

*For a man's work is himself and the greatest value of the best work lies in its bringing us into communion with the man we feel to be behind it, and in the end the men will show through, above and beyond his number.**

—SAMUEL BUTLER

IN 1922, when he had reached the age of seventy, Cajal retired from his work at the university. At first, he felt himself an exile, missing keenly the daily contact with his students and with his assistants in the laboratory. But recalling the decrepit, hidebound schoolmasters of his boyhood, he admitted to himself that the law that forced him to retire at seventy was wise as well as inexorable.

This was his jubilee year—he had taught for thirty years in Madrid—and many unsought honors were thrust upon him. For one thing he was made life senator in the Spanish Cortes. A shower of tributes poured in from all over Spain and from Latin America. One of the most moving to Cajal was the printing of an honorary volume written by his pupils and friends at home and abroad. It was his associate, Dr. Francisco Tello, who carried the responsibility for assembling the materials, getting them ready for the printer, and reading the proofs.

Another honor bestowed on him at this time was the Echegaray

* The quotation above, from *Collected Essays*, Vol. 1, page 218, is used with the kind permission of the literary executors of Samuel Butler and of Jonathan Cape Limited, London.

Explorer of the Human Brain

Medal, conferred on May 7, 1922, by the Royal Academy of Science in a session presided over by Alfonso XIII. Still another was a monument, designed in the Greek style, erected near his favorite walk in Retiro Park. The statue of Cajal is flanked by symbolic figures of life and death in bas relief. Cajal is looking down into a pool of water, representing the primordial fountainhead of life. Lovely fountains adjoin the monument, adding to its beauty. It is said that Don Santiago never entered the Retiro after the statue appeared. As always, he was embarrassed by such open acknowledgment of his fame.

Upon his retirement, the Government appropriated a large sum for the construction of a biological research center to be named in his honor the Instituto Cajal. It was built on the hill of San Blas near the Astronomical Observatory and inaugurated in 1932. The old Institute over which Cajal had presided while teaching at the university had been on the third floor of a building adjoining the Museo Antropológico on the corner of the Calle de Alfonso XII and the Paseo de Atocha. Much of Cajal's work had been done in the library there and in the small room next to it—a room lined from floor to ceiling with books. Jealously separated from the others and placed together on a single shelf were Cajal's own writings and those of his pupils. The magnificent building that houses the new laboratory came too late for Cajal's work. Besides, it was too elegant for him—he never felt at home there. It became the new headquarters for the school of Spanish histologists he had founded. Few foreign students have gone to it. The unfamiliarity of the language and of the customs of Spain, and the almost constant civil wars, have prevented its taking its proper place among similar institutions elsewhere in the world. In spite of Cajal's enormous work, his country has remained outside the main current of scientific advance.

Fernando de Castro describes Cajal's daily life after his retirement from active teaching.

After his jubilee in 1922 the order of his life was changed but little. Nevertheless, after the inauguration of the new laboratory in 1932, the master stopped coming almost completely. In the afternoons he could be seen at the Institute, but briefly. He didn't come to work but to visit. At about that time he installed a little private laboratory in the basement of his house. His last scientific work issued from there. There too he gathered together his magnificent library of more than 8,000 volumes and his marvelous collection of preparations and histological drawings, shining proof of the continuing activity of a great intelligence.¹

Though his visits to the Institute were fleeting, he could often be found in the favorite haunt of his university years—the café at the corner of the Plaza de Atocha. From there and from his home he directed the work of his students, seeing to it that their papers were published in French so that they would not suffer as he had from the barrier of language. Most of his time was spent in restless writing, elaborating his earlier work and advancing further evidence in support of his neuron doctrine.

In the 'twenties, when Cajal was already in retirement, Dr Wilder Penfield (later to become Director of the Montreal Neurological Institute) went to Spain to work at the Instituto Cajal under the direction of Pío del Río Hortega. He gives an illuminating picture of his first meeting with Cajal.

In America it had been rather difficult to explain how one could profitably spend six months in Spain learning new methods of medical research. But here in Madrid, Cajal, the winner of the Nobel Prize, was a figure much talked about though rarely seen. His name seemed to be a password, for had we not gained entrance into a pension heretofore restricted to Spaniards by mentioning that I had come to work under the great scientist? In like manner did we not secure the little *piso* for a permanent residence? The magic of his name made introductions easy and conversation immediately absorbing and satisfactory to

¹ Personal communication to the author. Translated from the Spanish.

the Spaniard, who welcomes above all else a tribute from abroad to the culture and intellectual distinction of his race

In university and scientific circles, Don Santiago, as he is called, seemed to be a sort of dean, and censor, to educational reformers, a much needed ally, and in politics a figure whose power is recognized even by the dictator Primo de Rivera. The peasant and the townsman understand nothing of his scientific work. It is enough for them that from foreign lands have come prizes and homage to this son of Spain, that he exhorts them to the stern virtues of their great ancestors and is himself a sign of the return of greatness to their land.

My first meeting with Cajal made a deep impression on me. It was in the library of his laboratory, and I found him sitting as though in dejection, with head fallen forward on his chest so that only white hair and beard could be seen. His long arms hung down almost to the floor. As I hesitated in the doorway, he started up and came forward with the graceful courtesy common to his race. With quick comprehension in his dark eyes, he welcomed me as a foreign pilgrim to the laboratory and spoke of his great desire that the outside world should know of the achievements of the little group of scientists about him. Placing his hand on a shelf that held his own publications and those of his pupils, most of them in Spanish, he said with much feeling in his voice, "These books are unknown abroad. Scientists will not read Spanish. Almost every week I learn from German or American journals that men are rediscovering what I did long ago." With increasing agitation he expressed the fear that the Spanish school of neurology would be ignored and would disappear after his death. Then with an abrupt change of manner, he took my arm and added, "Let me show you the laboratory. And I have some photomicrographs in color which you will like to see." This first interview roused a desire to know more about the man—a desire easily satisfied, for his admirers were glad to talk, and there were his popular writings and autobiography.

Cajal, Spain's first great scientist, is a man whose genius may be compared to that of Pasteur. He comes, like Pasteur, from the people and developed spontaneously in his native land.*

* From *Archives of Neurology and Psychiatry* 16:213, 1926. By permission of Dr. Wilder Penfield and the American Medical Association.

DICTATORSHIP IN SPAIN

DURING ALL THESE YEARS—since 1909—the costly campaign in Morocco had dragged on. If Alfonso had had any success in this enterprise he might have been able to salvage some remnants of his early popularity. But luck was against him. In July, 1921, the Spanish forces at Melilla were annihilated with a loss of 12,000 men. Abdel Krim, the native chieftain, exulted, while Alfonso's General Silvestre fled in disguise and later took his own life, unable to bear the disgrace of so colossal a failure. The war in Morocco was sapping the brief prosperity that Spain's neutrality in the European war had brought. At this point, Italy rebelled against her parliamentary government and accepted the dictatorship of Mussolini. Alfonso was quick to see advantages for himself in the creation of a similar situation in Spain. Many of his subjects had shown that they were tired of the fiction of a two party system that had no basis in reality. The king too was tired of the undercurrents of unrest. He had sworn to uphold the Constitution and therefore could not revoke it. But it was within the power of his people to do so. It was upon their doing just that, with adroit guidance from the proper sources, that Alfonso now built his hope for his own future security.

By 1923 Spain was at a low ebb. Abdel Krim was now master of the Rif, and the Spanish settlements of the coast were at his mercy. Still the hated war went on. Discontent at home was becoming more outspoken. Anarchy was again coming up from underground. Enterprising Cataluña was openly making every effort to disentangle herself from a downtrodden country whose destiny she no longer wished to share. It was under cover of such chaos, with the army behind him, that Primo de Rivera, one of Alfonso's ministers, made his coup d'état on September 14.

Don Miguel Primo de Rivera had been born in 1870, the nephew of the general who had secured Madrid for Alfonso XII in 1874. He was fully aware of the popular feeling that the par-

Explorer of the Human Brain

liamentary system as practiced in Spain was a mockery and had best be done away with since it merely served to conceal the machinations of the *políticos*. Profiting by this mood, Primo made his plans. The king was in San Sebastian on September 13, 1923, but the other ministers must have warned him of Primo's projected coup. Besides, Primo's purpose was widely known. He had issued a manifesto and at noon on the fourteenth he was to be asked to form a government. The king was back in Madrid early that day, but all went on as planned.

The dictator was accepted by the majority of the people with a feeling of relief. Mussolini was rapidly rising to undisputed power in Italy and to prestige throughout the Western world. Many felt there was something to be hoped for from his imitator in Madrid. The military dictatorship did bring order. Strikes ended. So did attacks on the king and on his representatives. The police once again commanded the respect of the people.

According to the Constitution of Spain, after one parliament had been dissolved, the king was required to form another within three months. But month after month went by and Alfonso did nothing to restore parliamentary government. In later years he claimed that he had expected order could be restored within three months and, when he found it could not, he had intended to obey the constitutional requirement as soon as it was safe to do so. But there is evidence that he too had succumbed to the idea of the rule of a strong man, by force, as the "wave of the future" and approved of what was happening even though his own power had been curtailed by it.

Under Primo's administration the war of the Riff came to an end. Abd-el-Krim had threatened France as well as Spain, and through the combined strength of the French and Spanish forces under the French leader Lyautey,² the Moorish chieftain was at

² Louis Hubert Gonzalve Lyautey (1854-1934) French marshal. Sent by France to Morocco as high commissioner and resident general to quell disturbances and to consolidate the recently declared French protectorate (1912).

last subdued Alfonso's prestige rose again. He had identified himself with dictatorship and dictatorship triumphed everywhere. In 1925 he re-established Primo's power. The majority of his people were behind him when he did this. But gradually Primo began to lose his hold. He never succeeded in establishing Spain on a sound financial basis. Prices rose. The purchasing power of the peseta fell, impeding foreign trade. Tariffs and taxes were sky-high. In the face of all this, when Primo attempted to bring about reforms in the army he was done for. He had tried to end the vicious practice of promotion by seniority alone, an abuse that had been railed against as long ago as the days when Cajal was sent out as a young doctor to Cuba. Those entrenched in high army posts did not relish Primo's efforts to change a situation they found so satisfactory to themselves. Losing the support of the influential officers in the army, Primo soon lost the backing of the king and of the people.

In 1929 when depression settled down over the world, Spain grew restive under the discipline of the dictator. Charges that Alfonso had broken his oath of office and betrayed his people when he had put aside the Constitution were loud-spoken now. There were student demonstrations at the universities (Cajal was witness to a number in Madrid) and much agitation against the king. The fact that three of his sons were victims of hemophilia and one was a deaf-mute was held against him. Unsavory rumors were spread abroad about his private life. Though now a mature man, Alfonso was still the dashing *caballero*, the romantic gallant, the carefree sportsman, having little in common with the thoughtful or the intellectual elements in his country. He even banished to the Canary Islands the leading philosopher of Spain, Unamuno,³ a professor at Salamanca, and imposed a rigid censorship of the press.

Primo de Rivera's dictatorship fell in 1930 after six years and

³ Miguel de Unamuno y Jugo (1864-1936) Spanish philosopher and man of letters. Author of *The Tragic Sense of Life*, *The Agony of Christianity*, etc.

four months. The decline in his prestige had come quickly. The reaction arose in part from the democratic forces within Spain, in part from the radicals, who during the years of his supremacy had organized strong propaganda against him. Though the economic stresses of these years were felt everywhere in Spain, the tension was greatest in Barcelona, and the city became a vortex of revolt. Primo resigned from his office in January, 1930, without telling the king of his intention to do so, later explaining his action as a necessary precaution to avert revolution. But Alfonso never forgave him, although Primo's going offered him a new means of trying to save his own position. Rivera went into voluntary exile in France, a broken man. In two months he was dead.

The king's own position was now being undermined by the general lack of faith in him owing to his inability to follow any consistent policy. Besides, the people were swinging back to a respect for constitutional government. And since the war years and the dictatorship had brought Spain a certain amount of financial and commercial prosperity, and with it a stronger middle class than ever before in her history, this time democracy might have succeeded. Alfonso seemed to be unaware of these strong currents flowing around him. For on the evening of January 28—the very day on which Primo officially resigned his office—Alfonso established another dictatorship with another general at its head—Berenguer—a man who had made a name for himself in the Riff war.

It seemed to Cajal as to all the impatient Spanish republicans and reformers that there would be no end to these military dictatorships. There was nothing to be hoped for from the coming elections, they knew how well the *políticos* could mold those to their wishes. The situation grew worse—or so the Liberals thought. Though the Berenguer government was not tyrannical at first—it was feeling its way—within the ten months it lasted it had dealt peremptorily with all disorder, had closed several universities, had outlawed strikes, and had continued the existing stern censorship.

of the press. In spite of its vigilance, there were riots in Madrid in November and in Jaca the next month. The republicans had organized under the leadership of Alcalá Zamora, Miguel Maura (son of the former Prime Minister), and the Socialist veteran Lerroux. These three formed a program for civil war.

At this point even the army was not unanimously for the king or his appointed strong man, many had been won over to the republican side. Revolt broke out first in a little village in the Pyrenees, then spread to the large cities. Airplanes flying over Madrid bearing the red flag of revolution dropped pamphlets foretelling the downfall of Alfonso. At once the king and his ministers invoked martial law. The revolt proved immature, Zamora was thrown into prison as a traitor, and some of his followers were shot.

The intellectuals now took up the struggle, Cajal wholeheartedly among them. Ortega y Gasset,⁴ Pérez de Ayala,⁵ and Gregorio Marañón⁶ published denunciations of the decadent monarchy, declaring it totally unequal to the task of regenerating Spain. Though Alfonso's confidence was still unshaken, facts were soon to prove that his real power was gone. He no longer caught the imagination of the young or won the undivided allegiance of the army. The aristocrats who did back him amounted to little politically. Most important of all, the people now saw clearly that he had little love for the Constitution and wanted to rule as an absolute monarch. And at this moment in world history absolutism was distinctly out of style.

⁴ José Ortega y Gasset (born 1883) Spanish philosopher, writer, politician. Author of *The Revolt of the Masses*, etc.

⁵ Ramón Pérez de Ayala (born 1881) Spanish man of letters, poet, novelist. After 1917 moved to Buenos Aires, and since then a figure in Argentine literature.

⁶ Gregorio Marañón (born 1887) Spanish physician, professor, and publicist. Educated at the Colegio de San Carlos in Madrid, disciple of Cajal's friend Olóziz. In 1908 at 21 he won the Martínez Molina Prize, awarded only once before—to Cajal. Worked with Ehrlich on the famous 606 (arsphenamine-copper preparation used in the treatment of syphilis—salvarsan).

THE SECOND SPANISH REPUBLIC

ON SUNDAY, April 12, 1931—to the genuine surprise of the monarchists—the people voted overwhelmingly for a republic. At five o'clock that day an emergency meeting was called to discuss what to do in the face of this unprecedented situation. The republican leader Alcalá Zamora (who had been released from his prison sentence on the ground that one could not be branded as a traitor for rebellion against a Constitution that was not in force) went to the palace to demand Alfonso's abdication. Zamora knew the palace well, twenty-five years before, he had been Alfonso's secretary and wise counselor. He warned the king that he was in great danger and suggested that he flee from Spain by way of Portugal, pointing out how strongly popular feeling was now aroused against him. On Monday, the next day, a throng surged to the palace gates to force the king's withdrawal from office. If he refused, they threatened, there would be a mass attack on the royal household. Madrid blazed with the red flags of revolution.

Alfonso signed a paper suspending his prerogatives as king—not quite a complete abdication, and he also agreed to leave Spain. On Tuesday, April 14, he bade goodbye to his wife and children without emotion, assuring them that he was leaving the country only to avert immediate civil war. He was confident that he would one day return to rule again. With a few companions he departed from the capital in a car sent for the purpose from the Ministry of the Marine. It was followed by a second car carrying several members of the civil guard. As soon as the king had gone, the soldiers protecting the palace withdrew and the red flag was hoisted over it.

The queen was to leave the next morning with her children. Their luggage was packed hurriedly while the revolutionary mob milled about in the square outside. The Prince of Asturias was ill from the exhaustion a recent hunting trip had caused him. Ena

was terrified that the populace would storm the palace and that they would all be murdered in their beds. But the mob was orderly. No such attempt was made. When morning came, the royal family left the palace by a secluded door and went to the Escorial, where they were to take a private train for the border. Once there, the Prince of Asturias had to be taken aboard the train on a stretcher. With tears streaming down her cheeks, the queen took leave of her ladies in waiting.

When the refugees at last reached Paris, they were noisily welcomed by the French throngs that had gathered at the station to catch a glimpse of them. The queen was worn out. It is said she looked like a sleepwalker, clutching in a nervous hand a bunch of red and yellow tulips—the royal colors of Spain. Meanwhile Alfonso had gone by cruiser from Cartagena to Marseilles, where he arrived at six o'clock in the morning, and then took the train for Paris. In a few days the family was reunited and installed comfortably by their French hosts at Fontainebleau.

Though the Second Spanish Republic (1931-35) had thus been established without bloodshed, its whole course was one of strife. Strikes of workers were almost constant and there were frequent attacks on the clergy and much confiscation of Church property by force. The new Constitution that had been drawn up by the Cortes under the premiership of Zamora declared Spain to be "a republic of workers of all classes with power emanating from the people." There was now no state religion. Freedom of the press, universal suffrage, and compulsory elementary education were proclaimed. Titles of nobility were abolished in the sweeping movement to wipe out all vestiges of the old order. A bitter debate over the question of the nationalization of Church property led to a political crisis that brought the resignation of Zamora, with his Home Secretary, Maura. Don Manuel Azaña, war minister, became premier in October, 1931. At this time a hated law was passed "for the defense of the republic" permitting the suppression of many cherished individual rights ostensibly for the common good. Strict

Explorer of the Human Brain

application of this law led to the interdiction of newspapers, the imprisonment of alleged radicals, and other measures that left the people less freedom than they had enjoyed under the dictatorship

The intellectuals (Cajal among them) chafed at this oppression by the republicans, whose cause they had championed so recently. Soon business declined and the exchange collapsed. Tourists and aristocrats jostled one another at the frontier in their haste to escape into France. Unemployment was widespread. There was bitter suffering among the poor. After six months of republican rule, Spain was more disorganized and chaotic than before.

During the next few years the trend was more and more to the Left until the Government became chiefly Socialist. In the years 1931 to 1933 oppressive restrictions were to a large extent abandoned and hope of a stable democratic government stirred again. It was soon to be dashed by a period of lethargy and depression, which lasted from 1933 to 1935.⁷

⁷ In July, 1936, Azaña became head of the group of parties that had banded together to win the election, calling themselves the Popular Front, after a similar movement in France. Turmoil was unleashed again. Alcalá Zamora, Prime Minister at this time, was deposed for having unconstitutionally dissolved the Cortes. Azaña became the new premier. He proved quite unable to cope with the general disorder and to impose any discipline or control over the conflicting groups. Spanish fascism grew in this fertile soil—in the same way that republicanism had grown before it—as a protest against the practical usurpation of power by the extremists.

The Spanish Civil War, soon to follow, was touched off by an army mutiny in Spanish Morocco led by General Francisco Franco. The mutiny spread to the mainland, and within forty-eight hours all Spain was in tumult. In this state of affairs Franco assumed power on October 1, 1936. Azaña was president during the war years, which lasted from 1936 to 1939. On March 28, 1939, 200,000 Nationalists marched into Madrid. They met no resistance from the republicans, who by now had to admit complete defeat.

Alcalá Zamora died in Buenos Aires on February 18, 1949, at the age of 71. The Franco Government had sentenced him to the loss of his nationality and of all his Spanish property.

CAJAL'S DECLINING YEARS

FROM HIS QUIET RETREAT in Amanuel Cajal observed with sadness the upheavals of these years of dictatorship, revolution, turbulent republicanism, and economic débâcle. He lived to the age of eighty-two, his last four years darkened by the loss of Doña Silveria, his loving companion for fifty years (She had died in 1930 at the age of seventy-six.) He continued his writing in seclusion and at the same time carried on the directorship of the Institute. He wrote almost up to the last day of his life, chiefly to confirm and consolidate the work of earlier years. He prepared a book on microtechnique in collaboration with Dr. Fernando de Castro, and two other books were completed shortly before his death: a new collection of *Chácharas de café* (Conversations at the Café) in 1933, and his delightful *El mundo visto a los ochenta años* (The World as Seen at Eighty) in 1934.

In this book, the last of his literary works, he described the onset of the arteriosclerosis that harassed his later years. He had observed the course of his disease for over a decade and recorded his sensations. At the beginning it did not interfere too seriously with his normal activities. He continued his work at the university and at his home laboratory and made his usual visits to the café, where he was always ready to discuss everything in heaven and on earth with his old earnestness, wit, and vehemence. Perhaps with a bit too much of the last. Suddenly his condition became much worse. He had violent headaches and finally his blood pressure soared so high that he went to see a doctor friend to ask for advice. Recognizing the disease as arteriosclerosis of the brain, the physician advised moderation in work—even the abandonment of all work for a time. But to Don Santiago idleness was worse than death. He would study his disease and record his symptoms, but he would not follow his doctor's recommendation to the letter. His recalcitrance seems to have done him little harm. His mental faculties never dimmed. The clarity of his thoughts and the precision with

which he expressed them even seemed to improve as he grew older To the end his salty humor, though sometimes mingled with wistfulness and a touch of Latin cynicism, never died out in him To this his *World as Seen at Eighty—Memoirs of an Arteriosclerotic* amply testifies

His old friend of Valencia days, Don Amalio Gimeno, writes

Hardly had he finished *El mundo visto a los ochenta años* when Cajal announced other works he was planning One, as I recall, was to deal with the mystery of the hereafter He used to think about that a great deal and, twisting a famous phrase about, he would say that he would like to look death in the face just as he would have liked to look squarely at the sun if Nature had given him a different sort of retina He did not stop to think that perhaps in the world beyond one can see death face to face *

Dr Fernando de Castro writes ⁸

During the last years of his life—that is, from 1930 to 1934—Cajal's chief preoccupation was the perfecting of his chapter on the neuron theory for the book to be edited by Bumke and Foerster [*Handbuch der Neurologie*, Vol 1, Berlin, Springer, 1935] He was eager to summarize all that had been written for and against his concept of the substantial discontinuity of the nervous cells and their dynamic dependence through the contact of some elements with others Some days after his death, in October, 1934, the completed draft of that chapter appeared in the review of the Instituto Cajal

In this period he began other books of a philosophical and literary character instead of going on with his series of scientific works, which he left unfinished With the exception of *El mundo visto a los ochenta años*, which appeared a few days after his death, the philosophical and literary manuscripts were lost during the civil war His son Jorge had been taking care of them and his house was invaded by evacués Nevertheless, I still remember the titles of some of these writings *The Mystery of the Tomb* and *Hallucinations and Dreams*—a theme which

* *Boletín*, Academia Española, Madrid, October 21, 1934, pages 7-18

⁸ Personal communication to the author Translated from the Spanish

fascinated him all his life (On awaking in the morning he would always jot down the dream he had the night before, if he could remember it) Another work was *Notes on Histological Psychology, Hypnotism, and Suggestion*

He was greatly interested in the conversations, acts, and thoughts of mediums In Zaragoza he came to know a woman who claimed to be a medium, an extraordinary one, better than the famous Palladino⁹ Since she came from a very humble family and completely lacked all economic resources, she supported herself by allegedly transmitting the thoughts of the spirits of famous Germans She gave their messages in correct German, a language which she had learned by herself, although she did not admit it Cajal invited her to come to live in his house with a view to carrying out some experiments on spiritism, and he arranged with her the salary he would pay her for doing this This woman, who said she was constantly inspired by the Archangel Gabriel, claimed that he answered questions through the spirit of a sister of hers, a nun, now dead for some time, whose materialization appeared in the shadows during the séances The master soon discovered that the figure that appeared in the shadows was none other than that of the medium herself She would appear dressed in a costume she had prepared with the greatest care, converting her ordinary garb into a nun's habit She had also managed to produce a spectacular change in her face by means of pieces of plastic that she stuck into her mouth and nostrils

In 1932 Dr Wilder Penfield made a visit to Cajal in the company of Dr Pío del Río Hortega Don Santiago had a cold and was propped up in bed with pillows behind him, busily penning a manuscript. Books were piled high about him and the wall near his right hand was splattered with ink He was preparing an article—one of the last he was ever to write—presenting a defense of

⁹ Eusapia Palladino (1854-1918) Italian medium celebrated in the field of psychic research Was studied in Europe by Professor and Madame Curie, by Cesare Lombroso (converting him to a belief in spiritism), and by the French philosopher Henri Bergson, who reported favorably on her genuineness, and in America by numerous distinguished psychologists, one of whom—Hugo Münsterberg of Harvard—caught her in trickery, so that she was thenceforth discredited generally

Explorer of the Human Brain

his neuron doctrine The article is his *¿Neuronismo o reticularismo?* (Neuronism or Reticularism?), which appeared in 1933 in the *Archivos de neurobiología* He was deaf and feeble, but his black eyes still blazed under their shaggy brows

His health grew gradually worse Always troubled with insomnia, now he hardly slept at all Though very weak physically, he kept the full vigor of his intellect almost to his last day He would gladly receive his children, his grandchildren, and friends, and would tell them about the work he had been doing in his solitude or would talk over the momentous events taking place in the world outside his sick room

On the evening of October 17, 1934, at 11 o'clock, he died Those who were at his bedside in the last hours testify that he had no fear of death His life ended nobly His funeral was simple, as he would have wished it to be It was attended by throngs of people from every class of Spanish society His body was buried in the Necropolis of Madrid beside that of his wife, as he had asked Many honors were paid to his memory, one being a special postage stamp showing him at his microscope And—what would perhaps have pleased him more—a complete republication of his works was undertaken by the Spanish Government

In *The World as Seen at Eighty* he expresses this thought on dying "When facts are faced squarely, we must admit that it is not so much the thought of our own death that grieves us as the realization that by it we are snatched from the bosom of humanity and thus robbed forever of the hope of seeing the unfolding of the heroic struggle constantly being waged between the mind of man and the blind energy of natural forces "

For Cajal the long battle had ended

12. Summation and Appraisal— by Way of Epilogue

*What then remains? Care, care, and patience, and simpli-
fication, and hardiness, and last of all—dear reman-
der—the flames to be held of and laid with.**

—A. C. BRINSON

NEURONISM AND ITS IMPLICATIONS

THE MAN who created the *Cajal* was in a country where science was neglected and even despised; he had to be the one to furnish modern neurology with so many new facts and such well substantiated theories as the last thing one might expect. Study of the minute anatomy of the nervous system would seem to call for the finest of equipment and a delicacy of technique that is difficult to achieve even under the direction of a skillful teacher. Yet when *Cajal* began his work he had only the most meager equipment and nothing but foreign textbooks to guide him. The patience needed for the meticulous detail of preparing sections for microscopic study is enormous. Only those who have attempted many times to follow such directions as textbooks offer, and have failed again and again because they neglected some seemingly trifling matter, can fully realize how trying such work can be. In the early years, too, *Cajal*

* The quotation above, from *The Silent Isle*, is used with the kind permission of G. P. Putnam's Sons, New York. The book was originally published by Smith, Elder & Co., London.

Explorer of the Human Brain

had to work without the stimulus and reward that come from original research and discovery. For he was occupied at first only in repeating the observations others had made. He worked for five years in obscurity without contact with the leaders in histology outside Spain and without the incentive of emulation. Yet his findings were to revolutionize neurology.

The core of Cajal's discoveries was his neuron doctrine. He pointed out to a skeptical world the fact that the basic unit of the nervous system is not the nerve *fiber*, as had been thought up to that time, but the nerve cell. Drs. Augusto and Jaime Pi-Suñer give a striking interpretation of the significance of this concept, which in the 'eighties was pure heresy.

The thesis that "everything communicates with everything" could bear some appearance of truth and clearness, but would have made absolutely impossible the actual psychological notions about the nervous system with the concepts of facilitation, summation, and inhibition, which at that time were unknown terms. It particularly disagrees with the pregnant theory of the final common path. The valuable help lent by the learned Spaniard in destroying the reticular theory and laying the foundations for the theory of the final common path may well be considered his best contribution to the knowledge of physiology of the central nervous system.*

In the years to follow, the neuron doctrine became an established part of nervous anatomy. It was soon substantiated by new evidence gained from studies of diseases of the nervous system and it at once proved useful in giving medical men a deeper understanding than they had formerly had of the physical basis of many types of nervous and mental disorders. Cajal's discoveries constitute the basis of our present-day knowledge of the development and structure of the neuron, of the way in which the nervous impulse is transmitted from sense organ to central nervous system and thence to muscle or gland, of the processes of degeneration and

* From *Journal of Nervous and Mental Disease* 84: 525, 1936

Summation and Appraisal—by Way of Epilogue

regeneration of nerve fibres and of the localization of the various sensory and motor areas of the brain

Carrying his studies of the nerve cells and of the neuroglia of the brain still further, Cajal offered a reasonable hypothesis to explain the phenomenon of sleep and of the loss of consciousness under certain pathological conditions of the body. A series of neurons connect the brain, the physical basis of consciousness, with the external surfaces of the body which receive the stimuli from the outside world. On occasion these neurons contract—that is, the nerve cells draw in their prolongations as living protoplasm always does when it is irritated. If the contraction is sufficient to cause the neurons to separate from one another, all consciousness of sensation is lost because the paths of conduction are broken. This occurs naturally in sleep. But the same contraction may result from a blow on the head severe enough to make one lose consciousness or it may be due to toxic poisons within the body that affect the neurons. The same contraction occurs, too, when a person is fully anesthetized. Sometimes, however, only the more delicate neurons are affected—those through which intellectual processes are accomplished and sensations of pain are felt. These higher neurons are more sensitive to the action of narcotic drugs than are the lower neurons governing the vegetative functions of the body. The higher neurons continue in a state of contraction as long as the influence of the drug lasts, and therefore, by varying the amount given, the depth and length of the anesthesia can be regulated. Similarly, when a person is in a hysterical state, though the paths of conduction may not be interrupted, the neurons may make unusual and unintended connections. Such improper connection may leave parts of the body without sensation or may lead to abnormal sensations.

Cajal's neuron doctrine also helps to explain the mechanism of memory. Recalling one thing may block the pathway to another. It is a common experience for one to forget what he intended to say when his recollection of it is temporarily blocked by another

thought that crossed his mind at something he may have just seen or heard. Various sorts of injuries to the nervous system may affect the memory of certain parts of one's past life, as may also the subconscious suppression of painful memories—a phenomenon that lies at the root of the modern treatment of certain nervous and mental disorders through psychoanalysis. Observation of disordered mental states such as illusions and hallucinations have confirmed Cajal's theory as to the contracting and expanding of the branchings of the nerve cells, the blocking of the normal connections, and the occurrence of accidental, unanticipated interconnections that produce abnormal nervous response.

Cajal himself did not fully work out all these hypotheses, but he did hint at many of them. The important thing is that he established the essential anatomical facts underlying them and that his discoveries led other men to do research along these lines—research that proved more fruitful because of the new direction his work had given it.

In evaluating his contributions to human knowledge, one must take into account the diverse fields his discoveries touched and illumined. The new data on the intimate structure of the nervous system that he brought to light are admittedly of greatest interest to the histologist, the physiologist, the pathologist, and the surgeon. But they are of immense concern also to psychologists and psychiatrists, since detailed information about the structure of the nervous system, coupled with observation of its normal and abnormal functioning in health and disease, gives useful suggestions as to ways of coping with nervous and mental disorders. To a considerable degree it was Cajal's work that made modern neurosurgery and neuropsychiatry possible. How important a contribution this was is at once apparent when one considers the vastness of the problem of nervous and mental disorders in the world today. In the United States alone probably more than three million persons are victims of severe nervous or mental disease. It is difficult to determine just how many more are afflicted with the milder form of disorder

[266]

known as neurosis, but unquestionably it too causes an immense amount of incapacity and misery, representing an enormous economic burden and tragic human waste. Cajal's discoveries have a direct bearing on education because they offer telling hints as to effective methods of teaching and of learning. He has given a valid explanation of how we learn to perform certain acts more easily and quickly through practice and how the faculty of memory can be developed through training. The nerve cells involved in such learning do not increase in number, but the connections between them become more perfect through use. The pathways of interconnection become stronger and the cells may even acquire new branchings by which more diverse connections with other cells are made possible.

Cajal's law of dynamic polarization affirms that the cell body with its dendrites directs the impulse along a one-way course—toward the axon. The question at once suggests itself: What happens when several impulses coming from the dendrites compete with one another for right of way? In such cases, Cajal said, it is the cell body that determines which impulse shall have priority. He suspected that there might be a chemical action of some sort in this selectivity, but did not develop the idea. Years later, Sir Charles Sherrington and his colleagues of the Cambridge School of Physiologists offered a theory of chemical mediation of the nervous impulse.¹ The English physiologists also introduced the mod-

¹ Two theories compete for general acceptance today—the chemical and electrical. Perhaps both electrical and chemical elements are involved. Both theories postulate the accumulation at the synapse of an active principle—electrical or chemical—which, upon reaching a certain level, will stimulate the dendrites beyond the synapse. The delay at the contact point may be accounted for by the need to build up the required amount of electrical charge or the required concentration of chemical.

It has been observed that in the autonomic nervous system activity is accompanied by the production of chemicals—acetylcholine, sympathin, and related compounds—that stimulate muscles and glands. Acetylcholine is also found here and there in the central nervous system, particularly in those parts containing motor cells and axons.

ern concept of the *synapse*, the contact point between the axon of one neuron and the dendrites of the next one in the chain of connection. At the synapse a resistance is set up to the passage of the impulse from one cell to the next. The resistance may vary in degree from an almost imperceptible slowing down to actual blocking (inhibition). However great the resistance may be, the course of the impulse is irreversible, it must go on toward its destination or drain away.

Cajal's theory of nervous conduction has been validated again and again, notably by Cannon's² animal experiments on the reflex arc and Pavlov's famous demonstration that a dog to whom food is given at the same time a bell is rung will learn to salivate when a bell is rung even though no food is offered—through the operation of the now well-known conditioned reflex. These concepts lie at the basis of all modern educational and psychological thought, explaining the mechanisms of animal instinct and habit formation as well as of all human learning. They help to explain, too, the phenomenon of integration, the "oneness" of our consciousness in spite of the fact that it is constantly being bombarded by infinitely diverse stimuli from both inside and outside the body.

² Walter Bradford Cannon (born 1871) Boston physiologist. Cannon's discoveries with reference to the physiological basis of emotion constitute one of the greatest contributions to psychology and psychiatry in this century. From studies of x-rays of digestive processes in cats, he found that fear and rage interfere with the normal functioning of the smooth muscles and glands. The bodily changes produced by fear and rage he found to be of a sort that temporarily allow the individual concerned to make greater effort than usual. The heart beats faster, blood pressure is raised, the adrenal glands secrete adrenalin, enabling the body to fight harder or to run away faster—in other words, giving the human machine greater power for a short period. But there are other changes, as, for example, the cessation of the activity of the stomach muscles. The body neglects its usual functions to concentrate its full energies on the emergency that produces the emotion. When such emergencies arise rarely, they do no harm to the healthy body. But in our life today emotional upheaval often becomes chronic, owing probably to the many frustrations modern life imposes, since our society seems to awaken more desire than it is able to satisfy.

THE PERFECTING OF NEW
STAINING METHODS

THROUGH THE USE of Golgi's discarded silver stain—perfected in 1888, so early in his career—Cajal was able actually to see more of the nervous system than had the anatomists before him. It was because of this happy discovery in technique and his idea of applying it to very young or unborn animals whose nerve fibers had not yet myelinated that he was able to add so much in a field that had already been thoroughly worked over by the greatest anatomists of the century—a field so much worked over, in fact, that it seemed almost naïve to expect to find anything more.

Having made a startling beginning with Golgi's stain, Cajal proceeded to perfect Ehrlich's methylene blue and finally to devise new methods that were wholly his own. In 1903 he developed his reduced silver-nitrate stain, in 1913, the gold sublimate, by which the neurofibrils, hitherto elusive to microscopic study, could be clearly visualized and traced. This stain soon yielded valuable data on the structure of the astrocytes, star-shaped cells in the tissue of what Cajal called the "third element" of the nervous system. It was one of his followers, Pío del Río Hortega, working with various adaptations of Bielschowsky's³ method (staining axons and neurofibrils with ammoniacal silver), who invented the silver-carbonate stain and through its use obtained such clear pictures of the "third element" that he was able to make exhaustive studies of the microglia and oligodendroglia of which it is, in part, composed.⁴ These researches threw new light on the gliomas, tumors

³ Max Bielschowsky (1869-1940) German neuropathologist

⁴ Important today in the diagnosis of nervous disorders are Río Hortega's glia stain, which tints the cytoplasm of the neuroglia black, and Penfield's glia stain, which renders the oligodendroglia clearly visible. In studying a microscopic slide for diagnostic purposes, the physician or surgeon must follow an orderly procedure and hold to a definite point of view. After finding out what stain has been used on the tissue, he must look for the special structures that stain shows well. Tissue of the cerebral cortex tinted with

of the glia, or supportive cells of the nervous system, and have been of inestimable help to neurosurgeons in their understanding of these growths and in their efforts to extirpate them

Another direct medical application of Cajal's investigations—this one the outcome of his studies on nervous degeneration and regeneration and his procedures for producing expertly stained sections—is the *modern technique* by which the physician is able to aid the regeneration of injured nerve fibers and hasten the healing of a severed nerve. Instead of letting Nature work alone—slowly and often inefficiently—to repair traumatized axons, the doctor now puts them in direct contact with connective tissue or with the cut end of the nerve, if that is possible

CAJAL'S WRITINGS

MOST of Cajal's scientific works were written to serve as textbooks for students and they still rank among the best and the most authoritative. His chief treatises have become classics in histology and give completely original conceptions of cell structure in every part of the nervous system. For many years after his death investigators unfamiliar with his work continued to discover facts Cajal had already unearthed in the 'nineties. The best-known of his scientific writings is his *Textura del sistema nervioso* (Texture of the Nervous System) (1897-1904), which was revised and amplified in the French edition of 1909. After all the years that have passed since then, this is still the most complete and accurate description ever made of the more delicate nervous structures. His great treatise on the retina completes and supplements the investigations made in this field by such pioneers as Max Schultze, and his ency-

Cajal's stain, for instance, shows only the glia cells, tissue stained by Weigert's method shows the myelin sheaths. To obtain a more complete picture, sections treated with different appropriate stains must be studied serially

clopedic work on nervous degeneration and regeneration is the most comprehensive study of the subject to date

His books and articles—scientific and literary—approximate 286 His literary writings, such works as the *Cuentos de vacaciones* (Holiday Tales), *Psicología de Don Quijote y el quijotismo* (The Psychology of Don Quixote and Quixotism), *Recuerdos de mi vida* (Recollections of My Life), *Reglos y consejos* (Rules and Counsels), *Cuando yo era niño* (When I Was a Child), *Charlas* and *Chácharas de café* (Conversations at the Café), *Pensamientos escogidos* (Selected Thoughts), *La mujer* (Woman), *El mundo visto a los ochenta años* (The World as Seen at Eighty), are of such merit that an honorary degree was given him, in company with another noted Spanish writer, Menéndez Pidal, by no less an institution than the French Sorbonne Many of his writings have been regarded by competent critics as valuable additions to Spanish literature *Reglos y consejos* illustrates his literary style at its best.

THE SPANISH SCHOOL OF HISTOLOGY

ONE of Cajal's most significant contributions is the school of Spanish histologists he founded and inspired through his teaching and example To create such a school had been the ambition of his youth And at that unpropitious time, this must have seemed a project worthy of a second Don Quixote Even after the school had grown and prospered, he had fears—in the moods of despondency that came upon him with increasing frequency in his later years—that it would shortly cease to exist after he died Far from it On the first anniversary of his death, a new Laboratory of Normal and Pathological Histology was established at the University of Madrid The enrollment of the university increased strikingly in the years to follow, with a large proportion of the students enrolled in medicine Graduate study of scholarly caliber was made available

to promising students under the direction of men who had been trained by Cajal, many of them outstanding figures in the new Spain. Nothing would have given Cajal greater satisfaction than to see how well his disciples, and their disciples, carried on his work.

Throughout all his scientific productivity and in the midst of the many bitter controversies that raged about it during his lifetime, saddening his days, he never forgot the true aim of science as he himself had once trenchantly expressed it in his *Charlas de café*—"to elucidate the dark mysteries and unknown forces which surround us for the benefit of our children, and to make the world more agreeable and intelligible while we ourselves are forgotten, like the seed in the furrow." He used often to say that the real problem of Spain was a problem of culture. He had once scrawled that thought on a picture of himself hanging in the university laboratory. And he had added "If we Spaniards are to be numbered with the civilized peoples of the world, we must cultivate the desert of our land and the intellect of our people, thus salvaging through prosperity and mental vigor all those national riches that have been lost in the sea and all those talents lost in ignorance."

DON SANTIAGO THE MAN

NATURE had given Cajal many gifts. He was the greatest scientist Spain had ever produced and one of the scientific leaders of the world. He was also an artist of distinction, an authority on color photography, and a precursor in the revival of art that took place in Spain before the outbreak of the Civil War. He was a witty talker, a dynamic teacher, an admirable writer. Among the fortunate faculties he possessed were his ingeniousness, his artist's deftness, and the sharp power of observation the scientist shares with the artist. All these were indispensable to successful work in such a science as histology. So too were his patience, his perseverance,

Summation and Appraisal - by Way of Epilogue

his tirelessness, his urgent drive to do something of note. It is clear that his make up combined the prime requisites for the work to which reluctantly at first he devoted his life.

His capacity for work and the scope of his achievement were immense. Someone of his own kind summed it up wittily in the little verse

*A Castilla Aragon, el mundo le dio Colón,
A Castilla Aragon, el mundo le dio Ramón.²*

Van Cebuchten once summed it up succinctly too, in more serious fashion. "Cajal has given us the key with which to open up the mysterious cavern of the brain, and with it he himself has unlocked a whole new world - the world of thinking man."

Dr. Francisco Luján, while professor of psychiatry at the University of Turin, wrote what is perhaps the most apt of all the evaluations of Cajal and his work.

The case of Santiago Ramón y Cajal is certainly unique in history. In a cold and calculating, but yet indolent and almost hostile, this man succeeded by sheer force of talent and will and by inspired, indefatigable work in a field of scientific achievement as harmonious as a work of art and old enough to last for centuries. At the same time, he managed to stir up by his example and his teaching talent, unsuspected creative activity in a school in which the students in their turn were trained to become teachers of the first rank, changing the face of histology and medicine and shaking the somnolence of the universities in his country. And that was not all. Almost without wishing it scarcely paying any attention to politics, he exercised a tonic effect on the entire political life of his land, producing changes which, in the opinion of the world, refuted the old commonplace derogatory to Spain and gave that nation a new faith in its own power.

The work of Cajal is monumental. Without exaggeration it can be said that modern neurology owes to him above all others the enormous

² To Castile and Aragon, Columbus gave a new world,
To Castile and Aragon, Ramón gave the inner world.

Explorer of the Human Brain

progress realized in the last half-century a gigantic complex of facts and ideas from which present-day neurology derives its characteristic physiognomy Especially in the field of the morphology of the nerves, it can truly be said that Cajal, by himself alone, has produced more than all the other neurologists together methods, techniques of inexhaustible fruitfulness, work tools for all, numerous discoveries—even the least of which a scholar might be proud of, penetrating, synthesizing interpretations, both lucid and persuasive, that have worked like ferments on physiology and pathology No matter what branch of his subject a neurologist chooses, he must always have Cajal's work constantly before him and must invoke his name in the exposition of any facts or ideas whatever

He has set an example of wholesome nationalism, a nationalism that is not nourished on jealousy of neighboring countries and on blind negation of foreign values but is concerned with raising the repute of one's own country through worth-while work His was a strong and noble character without taint of self-seeking *

Cajal was not only admired by his colleagues and his followers—they loved him too The very fact that he was known among them simply as "Don Santiago" tells something of their affection Moreover, his students sensed keenly the greatness of the spiritual heritage he left them Again and again they mention his endless kindness They tell how ready he was with quick encouragement whenever the vicissitudes of life had made them downhearted about their own work, how ready he was with his help and protection when they needed it. "And to the greater glory of his spiritual excellence," wrote Fernando de Castro, "he always made it a point not to exert pressure on his pupils by influencing them with any ideas of his in their interpretations of the results they obtained from their own original researches" ⁶

* From *Revista di patologia nervosa e mentale* 45 v, 1935

⁶ Translated from the Spanish of the article on Cajal in the volume of *Archivos de neurobiología* dedicated to his memory 14 833, 1934 Cajal's last scientific paper had been written for this same journal and appears in 13 217, 1933

Summation and Appraisal—by Way of Epilogue

Sir Charles Sherrington in the obituary of Cajal that he wrote for the Royal Society of London pays him this warm homage:

He has come to stand in some sort as a symbol of national cultural rebirth. Despite, perhaps partly because of, his retired and simple life and his advanced years, he and his scientific devotion and prestige were taken to typify by many of his fellow countrymen what a new Spain might cherish and accomplish, he was taken as a sort of forecast of what a new Spain should stand for. In this sense he caught the national imagination. Barely note, bore his effigy, a postal issue was to distribute his likeness millionfold as a national emblem. He deprecated the proposal at the time, but after his death it was done. We may well believe that such a memento, at once national and democratic, would have touched Don Santiago's virile heart. It is a tribute which gives evidence of the position accorded him by the Spanish, a position accorded him with the sympathy and applause, indeed, of the civilized world entire.*

It was also on the occasion of Cajal's death that Dr Wilder Penfield wrote of him:

Now that the end has come, his life and achievement loom large in the history of neurology. He was a many-sided genius impelled by that mysterious 'whisper' that comes to God's chosen few that draws them ever onward to explore beyond the horizons of existing knowledge, without rest and with no need for recompense other than to know that they have entered the promised land of discovery.†

There could be no more fitting epitaph.

* From *Obituary Notices of Fellows*, 1935. By permission of Sir Charles S. Sherrington and the Royal Society of London.

† From *Archives of Neurology and Psychiatry* 33: 172, 1931. By permission of Dr Wilder Penfield and the American Medical Association.

Selected Bibliography of Cajal's Works

Manual de histología normal y técnica micrográfica (Manual of Normal Histology and Micrographic Technic) Textbook for students, illustrated with 203 original drawings 1st edition, Valencia, 1889, 2d edition, 1893

Manual de anatomía patológica general seguido de un resumen de microscopia aplicada a la histología y bacteriología patológicas (Manual of General Pathological Anatomy Followed by a General Résumé of Microscopy Applied to Pathological Histology and Bacteriology) Textbook illustrated with numerous original drawings in black and in color 1st edition, Barcelona, 1890, later editions, Madrid, 1896, 1900, 1905, 1909, 1918, 1922

Les nouvelles idées sur la fine anatomie des centres nerveux (New Ideas on the Minute Anatomy of the Nervous Centers) With numerous illustrations Preface by Dr. Mathias Duval, Paris, 1894

Die Retina der Wirbelthiere (The Retina of the Vertebrates) With a preface by Dr. Greeff Berlin, 1894

Elementos de histología normal y de técnica micrográfica (Elements of Normal Histology and of Micrographic Technic) Madrid, 1897, 7th edition, 1931

Textura del sistema nervioso del hombre y de los vertebrados (Texture of the Nervous System of Man and of the Other Vertebrates) Classic on the subject, in 3 vols, Madrid, 1897, 1899, 1904

Selected Bibliography of Cajal's Works

- Reglos y consejos sobre la investigación biológica (Rules and Counsels on Biological Investigation) Speech read on the occasion of Cajal's election to membership in The Royal Academy of Exact Physical and Natural Sciences, Dec 5, 1897 Later published in book form, this work went through many editions and was widely circulated in the Spanish universities
- Cuentos de vacaciones (Holiday Tales). Pseudoscientific stories Madrid, 1905
- Studien über die Hirnrinde des Menschen (Studies on the Human Cortex) Leipzig, J Barth, 1906
- Studien über Nervenregeneration (Studies on Nervous Regeneration) Leipzig, 1908
- Histologie du système nerveux de l'homme et des vertébrés (Histology of the Nervous System of Man and of the Other Vertebrates) Translation of Cajal's classic work by Dr Léon Azoulay, his official French translator 2 vols, Paris, 1909-1911
- La fotografía de los colores fundamentos científicos y reglas prácticas (Color Photography Fundamental Principles and Practical Rules) Madrid, 1912
- Estudios sobre la degeneración y regeneración del sistema nervioso (Studies on the Degeneration and Regeneration of the Nervous System) Fundamental treatise on the subject. 2 vols, Madrid, 1913-1914
- Recuerdos de mi vida (Recollections of My Life) Cajal's autobiography 2 vols, Madrid, 1901-1917, 1923 (Admirably translated into English by Dr E Horne Craigie, Professor of Comparative Anatomy and Neurology, University of Toronto, Canada, Philadelphia, American Historical Society, 1937)
- Manual técnico de anatomía patológica (Technical Manual of Pathological Anatomy) Written in collaboration with Dr Francisco Tello, who did the greater part. Madrid, 1918
- Discurso leído con ocasión de la recepción de la Medalla Echegaray (Speech Read on the Occasion of Receiving the Echegaray Medal) May, 1922
- Charlas de café (Conversations at the Café) Thoughts on a wide variety of subjects, anecdotes, etc. 3d edition, Madrid, 1923

Selected Bibliography of Cajal's Works

- Técnica del sistema nervioso (Technic of the Nervous System) In collaboration with Dr Fernando de Castro, Madrid, 1932
- Regeln und Ratschläge zur wissenschaftlichen Forschung German translation of the Reglos y consejos, Munich, 1933
- Histology English translation of the Elementos de histología by Professor Fernán-Núñez from the tenth Spanish edition of Cajal's work, in collaboration with Dr Francisco Tello
- El mundo visto a los ochenta años (The World as Seen at Eighty) Anecdotes of later life, description of the symptoms of arteriosclerosis, etc Madrid, 1934
- Obras literarias completas, M Aguilar, Madrid, 1947

In addition to this vast production Cajal published during his long life about 265 scientific monographs covering the work of the years 1880-1933

*Bibliography of Sources**

Addison, William H. F. Ramón y Cajal—an appreciation, *Scientific Monthly* 31: 178, 1970

Article concerned with Cajal's later life from time of trip to England until his death in 1934

Antón del Olmo, Luis, and J. de Torres Bernal. Cajal—historia íntima y testimonio científico del cerebro humano durante su época, Madrid: El Pueblo, 1918

Book of 385 pages in the *Grandes Españoles* series. Largely a repetition of Cajal's *Recuerdos de mi vida*, supplemented by additional details about his family, later years, contacts with authors of the book, etc. A sincere appreciation of Cajal's genius and character. Dedicated to the doctors of Spain to whose knowledge Cajal made his unique contribution

Archivos de neurobiología 13: 833, 1933

Issue dedicated to Cajal's memory. Illustrated. Brief biographies and appraisals of his scientific work. Tributes from outstanding colleagues

Professors

F. de Castro (Seville), p. 833

Maximiliano Rose (Vienna), p. 865

G. Marinesco (Bucharest), p. 873

* Studied also in the preparation of this book were Cajal's complete works

Bibliography of Sources

C Schaeffer (Budapest), p 879

C Winkler (Utrecht), p 882

J Lhermitte (Paris), p 883

A Heymanovitch (Kharkoff), p 887

W Penfield (Montreal), p 890

E Lugaro (Turin), p 894

Et al

Several other universities represented by shorter tributes Genoa, London, Salerno, Munich, Giessen, Johns Hopkins, Brussels

Archivos de neurobiología 13 217, 1933

Article *¿Neuronismo o reticularismo?* by Ramón y Cajal Long article defending the neuron doctrine after giving a summary of arguments for and against it. One of the last writings to come from Cajal's pen, showing how large a part the defense of the neuron doctrine played in his life, from the time of its conception in his youth until shortly before his death

Aschoff, L Cajal, Zieglers Beitrage z allg Path 3 94, 1935

Obituary of Cajal with appreciation of his contributions to neurology

Athias, M Cajal, Lisboa Médica 11 831, 1934

Obituary of Cajal with an evaluation of the man and his work

Barker, L F Travel notes—Spain and Ramón y Cajal, J A M A 43 403, 1904

Recounts a vacation trip to Spain with a visit to Cajal's laboratory and a detailed description of the impression Cajal made on the author of the article Also an evaluation of Cajal's work and that of his adversary, Bethe

Buño, W Cajal, Anales, Facultad de Medicina, Montevideo, No 19, 1934

Obituary of Cajal with appreciation of his significance to Spain and to Latin America

Cortezo, Carlos, M Cajal, su personalidad, su obra, su escuela, El siglo médico 69 421, 1922

Analysis of the status of histological knowledge before Cajal, with an appraisal of the importance of his contributions in the light of this

Bibliography of Sources

of the cells of the retina and of the special cell structure of the retina of birds

Grote, Louis Rhyter Radcliffe Cajal, *Die Medizin der Gegenwart in Selbstdarstellungen*, Leipzig, Verlag von Felix Meiner, 1925, pp 1-46

Account of Cajal's life based largely on the *Recuerdos*

Gutiérrez, Avelino Homenaje a Santiago Ramón y Cajal, *Bol acad nac de med de Buenos Aires* 35 146, 1935

Appreciation of Cajal's work and of his character as a man, teacher, philosopher, patriot, prophet, scholar, writer, editor, and investigator An outline of the various stages of his scientific work A detailed analysis of his fundamental concepts and of the practical application of his discoveries

Hilton, William A Cajal's suggestions for scientific investigation, *Scient Monthly* 36 225, 1933

Article largely drawn from Cajal's *Reglos y consejos*, plus an analysis of the philosophy behind this advice to young researchers and its general applicability and usefulness

Jakob, C Santiago Ramón y Cajal, la significación de su obra científica para la neuropsiquiatría, *Semana méd* 42 529, 1935

Study of Cajal's contributions to a deeper insight into the structure and function of the nervous system and the direct bearing of this more profound understanding on modern neuropsychiatry

Jelliffe, S E Cajal, *Tr Am Neurol A* 60 234, 1934

Obituary with brief, interesting sketch of Cajal's life and a well-written appreciation of his work

Jiménez de Asúa, Felipe El pensamiento vivo de Cajal, Buenos Aires, Editorial Losada, S A, 1941

Readable summary of the neuron doctrine and of other basic concepts of Cajal

——— Cajal, *Revista de cultura y vida universitaria*, Univ de Zaragoza 12 323, 1935

Glowing tribute to Cajal's accomplishment in transforming Spanish science.

Jolly, M J Cajal, *Bull Acad de med de Paris* 112 523, 1934

Excellent account of Cajal's discoveries with reference to status of

Bibliography of Sources

- science in Spain when he began his work and to the new direction he gave the study of the natural sciences.
- Lorenzo Cordero Rivas y Cordero, *La vida de un sabio*. Madrid: Ediciones Nueva Riera, 1935.
- Readable account in 187 pages of Cajal's later years and death.
- A popularized description of his work, elements of great interest, a realisation of the scope of his effort at biology, logical, methodized evaluation through the representation of the basic concepts and of their significance to science.
- Lefora González R. *La vida de un sabio*. Madrid: Ediciones de la Universidad de Madrid, 1935. No. 1. Pp. 31-52.
- Carl's scientific life. Madrid: Tema F. No. 1. Pp. 31-52.
- An estimate of Cajal's scientific work, his work and his life. His scientific future has been especially for his work, his scientific analysis and summarizing talent, and the characteristics of his formation.
- Lancet, 1939, 1935.
- Obituary notice. Unsigned. Some interesting details are found in the *Recorders*.
- Lembach, M. V. *Santiago Ramón y Cajal*. New York: 1935.
- Book 23, 500, 1935.
- Summary of Cajal's work by a professor at Budapest. Interpretation of his permanent place in the world of science.
- Lera, G. *Cajal ha muerto*. Madrid: 1935. Su padre España no se ha enterado aún. *El mundo*, 1935, 32, 622, 1935.
- Enthusiastic review of Cajal and his work. Detailed and valuable analysis of his biography.
- Lieberman, Donatiano R. *La vida de un sabio*. Madrid: 1935.
- Short summary of Cajal's life, based almost entirely on the *Recorders*.
- Llana y Despuig, Enrique. *Evolution y superación en la naturaleza y la problema social*. prólogo por Dr. Santiago Ramón y Cajal. Barcelona: Administración, 1935.
- Book devoted to the study of the anthropological causes of the so-called social question: the moral and intellectual evolution of man in his relation to society. Introduction written by Cajal, who says in it that he has had little time to study this vast subject, he has, rather, studied the tiny cell in the garden of nature, leaving in

Bibliography of Sources

others its synthesis into social organisms. He gives his reactions to Dr Lluria's social philosophy Interesting sidelight on the man and on his approach to life

Lorente de N6, Rafael Transmission of impulses through cranial motor nuclei, *J Neurophysiol* 2 402, 1939

Article by one of Cajal's students, later connected with the Rockefeller Institute for Medical Research, New York City Sums up the electrical theory of transmission of the nervous impulse

Lugaro, Ernesto Cajal, *Revista di patologia nerviosa e mentale*, 45 v, 1935

Unusually fine evaluation of Cajal's life and work, with portrait of Cajal

Malo de Poveda, B El doctor Santiago Ram6n y Cajal considerado como literato, psic6logo, soci6logo y pol6tico, *Nuestro Tiempo*, Madrid, 22 105, 1922

Analysis of Cajal's views and activities as a man of letters, psychologist, sociologist, and politician Interesting sidelights

Marinesco, G La cellule nerveuse, Paris, Octave Doin et fils, vol 1, 1909, p 151 ff

Account of researches on nerve cells done by Professor Marinesco of Bucharest, with a preface by Cajal giving his estimate of Marinesco's work

McGuire, Elizabeth La infancia de Ram6n y Cajal, New York, Holt, 1925

A textbook for Spanish students in American high schools and colleges Deals only with Cajal's childhood as related in the *Recuerdos*, with an introduction by the author outlining Cajal's chief accomplishments and giving an estimate of his importance to the advancement of histology and nuerology

Medicina espa1ola 2 569, 1940

Cover carries a drawing of the head of Ram6n y Cajal Entire issue dedicated to his memory on the fifth anniversary of his death

Die medizinische Welt 10 1275, 1936

Account of Cajal's life and work with a review of the first edition of *El mundo visto a los ochenta a1os*, in which Cajal describes the onset of his own arteriosclerosis (which he observed carefully

throughout its course, recording his findings as an aid to medicine.

Misolexy, D. *Carl* Revista Hungaria 1923

Obituary of Cajal with evaluation of his work.

Negeotte J. *Cajal*, *Proc. zemed.* No 8, Dec., 1923, p. 368.

Obituary giving an appreciation of Cajal's achievement.

Neurological Biographic and Addie c. Neurological Institute, McGill University, London Oxford University Press, 1926.

Foundation volume published by the staff to commemorate the opening of the Montreal Neurological Institute. Biographical sketches of leaders in neurology presented for the purpose of giving clearer insight into the future of the science through study of its past. Foreword by L. W. Archibald. Preface by Dr. Wilder Penfield. Articles on Cajal by Dr. William Sprong (q.v.), who died his article was being to print.

New York Times, Oct. 27, 1923.

Obituary of Cajal Brief, not entirely accurate. (Microfilm Collection, New York City Public Library.)

Ochovenens I. *Carl* Anale Instituto de Biologia de Mexico, v, No 3, 1924.

Obituary of Cajal with a tribute of his significance.

Peña Vicente. Nota de duelo-muerte del profesor Santiago Ramón y Cajal, *Gaceta médica de Caracas* (Venezuela) 31, 305, Oct. 31, 1924.

Obituary of Cajal who had been a foreign corresponding member of this journal since 1903. Praising estimates of man and his work by Dr. Peña and also by Dr. Francisco Antonio Riquelme.

Penfield Wilder. Santiago Ramón y Cajal, *Arch. Neurol. & Psychiat.* 16, 213, 1926.

Account of Dr. Penfield's work in the laboratory of Dr. Pio del Rio Hortega, pupil of Cajal. Gives an admirable picture of Cajal's place among his students and colleagues. Includes a description of Dr. Penfield's first meeting with Cajal. The main facts of the *Recuerdos* are retold and are supplemented by new sidelights and anecdotes.

— Santiago Ramón y Cajal, *Arch. Neurol. & Psychiat.* 33, 172, 1934.

Bibliography of Sources

Fascinating new light on Cajal through anecdotes not previously published Excellent appraisal of the man and his work, by a visitor from America who knew him personally

Pi-Suñer, Augusto, and Jaime Pi-Suñer Ramón y Cajal and the physiology of the nervous system, *J Ment. & Nerv Dis* 84 521, 1936

Estimate of Cajal's place among the scientists of his day and those of the next generation His relations with Kolliker Sherrington's divergence from path charted by Cajal Conflicts with Gerlach, Golgi, Bethe Comments on which of Cajal's theories were refuted in a later age and which finally became established concepts in histology and neurology

Polak, Moises Pío del Río Hortega, 1882-1945 (pamphlet) Buenos Aires, Sept. 1947 Material also published in *Archivos de histología normal y patológica* 3 4, Sept., 1947

Detailed account of the work of Dr Pío del Río Hortega with reference to his contacts with Cajal, one of whose outstanding pupils he was

Psychiatrisch-neurologische Wochenschrift 37 597, 1933

Review of the German edition of *Reglas y consejos* (Regeln und Ratschläge) and an interpretation of Cajal's approach to neurological problems

Ramón García, Silverio Luis, and A Pardo García Ligero bosquejo de la obra científica realizada por Dr Santiago Ramón y Cajal, Madrid, Universidad Central de España, Facultad de Medicina, Trabajos de la cátedra de historia crítica de la medicina, 1934

Good estimate of Cajal's life and work

Río, A del Santiago Ramón y Cajal en la literatura de hoy, *Revista hispánica moderna* 1 97, 1935

Brief sketch of Cajal's life and work based largely on the *Recuerdos* Evaluation of his literary contributions

Rodríguez, A El premio Nobel y Ramón y Cajal, *El siglo médico* 54 102, 1907

Brief historical account of Alfred Nobel and the establishment of the Nobel Prizes Announcement of Cajal's winning the award in 1906 Description of the medal and the diploma he received

- Sabotta, J. Santiago Ramón y Cajal, München med Wehnschr 14
579, 1907
Brief account of Cajal's life and achievement with special refer-
ence to his winning the Nobel Prize
- Sense, T. Cajal, II Cerebro No 13, 1931
Obituary of Cajal with observations on his life and work
- Sherrington, Sir Charles Scott. Santiago Ramón y Cajal, 1852-1934,
Royal Society of London, Obituary Notices of Fellows, London,
1935, pp 425-441
Unusually fine account of Cajal's life and death with an evalua-
tion of the significance of his work, particularly his neuron doc-
trine. His role as precursor in the rebirth of Spanish science is
discussed. Also the achievements of his pupils and followers. A
general estimate of his place in world science is given
- (El) Siglo medico 9, 441, Oct 20, 1931
Obituary of Cajal entitled "Cronica luctuosa" Unsigned. Illus-
trated with many pictures of Cajal, including an autographed
portrait presented to the magazine. Article expresses the personal
grief of the staff of this journal. Reports the article on Cajal by
Carlos Cortezo (q.v.) published in 1922. Brief sketch of Cajal's
life chiefly indebted to the *Recuerdos*
- Soria, Dr. El quiasma optico en la escuela de Cajal, Archivos de
oftalmología 31 612, 1931
Detailed study with numerous diagrams, of Cajal's views on the
optic chiasma plus an estimate of his contribution to modern
knowledge of the structure and function of the eye
- Sprong, Wilbur. Santiago Ramón y Cajal, Arch Neurol & Psychiat.
33 156, 1935
Article written by a promising young doctor on the occasion of
the unveiling of 13 panels in the frieze of the entrance hall of the
new Montreal Neurological Institute, one of which is inscribed
with the name of Cajal. Brief but well written account of Cajal's
life and work, drawn largely from the *Recuerdos*, but supple-
mented by details on his later life and by an estimate of his
importance to neurology (See Neurological Biographies and
Addresses)

Bibliography of Sources

- Tello, J F Santiago Ramón y Cajal, *Anales de medicina interna*, 3
1059, 1934
Life of Cajal briefly outlined New details on his later years and
his influence in Spain Sincere appreciation by Cajal's most
eminent Spanish pupil and his successor as director of the Insti-
tuto Cajal
- Cajal y su labor histológica, Universidad Central (Cátedra
Valdecilla), Madrid, 1935
An unusually comprehensive study of Cajal's work during the
three main periods of his creative activity as investigator 1877-
1887, in which he did research in all branches of histology,
1887-1903, in which he studied the entire nervous system using
the method of Golgi, 1903-1934, in which he used chiefly the
methods he himself had devised, principally reduced silver nitrate
in its multiple forms
- Cajal, *Gaceta médica española*, Dec., 1934
Obituary of Cajal with sincere appreciation of his genius
- Cajal, *Anatomischer Anzeiger*, 80, No 1/4, 1935
Obituary of Cajal with warm appreciation of his greatness
- Tello, Valdivieso F Cajal, *Archivos de medicina, cirugía y espe-
cialidades*, vol 37, No 42, Oct., 1934
Obituary of Cajal with appreciation of his work
- Vargas, Martínez Profesor Santiago Ramón y Cajal, *Medicina de los
niños* (Barcelona) 35 289, 1934
Obituary with sketch of Cajal's life covering points not mentioned
in the *Recuerdos* Honors, monuments Appraisal of his character
development through the years and of his role as teacher, minister
of education, life senator, ophthalmologist, etc Comments on
Cajal's literary style
- Villaverde, J M Cajal, *Archives suisses de neurologie et de psychi-
atrie*, 1936
Obituary of Cajal with an evaluation of his lifework
- Cajal, *Ztschr f d ges Neurol u Psychiat*, 1936
Obituary of Cajal with an appraisal of his significance
- Walsh, J J Santiago Ramón y Cajal, discoverer in brain anatomy,
Sacred Heart Messenger, July, 1901, pp 599-608
An interesting account, popularized for the layman, of Cajal's
- [288]

Bibliography of Sources

work by a well known American physician, author, and lecturer, with special reference to Cajal's winning the Moscow Prize in 1900

Winkler, C. Cajal, *Nederl. Tijdschrift voor Geneeskunde* IV, No 44, Nov., 1934

Obituary of Cajal and appraisal of his achievement

ADDITIONAL REFERENCES*

Ann. esp. psychiat. di Perugi 28, 322, 1934

Ciencias 3, 217, 1936 (Brites)

Ciencias mod. (Madrid) 3, 1, 1896 (Peláez)

Corresp. med. (Madrid) 35, 341, 1900 (Murquez)

Rev. méd. argent. 40, 5, 1935

Rev. san. mil. (Madrid) 24, 323, 1934

Rev. frenopiat. españ. 5, 3, 1907 (Sicimella)

HISTORICAL REFERENCES

Altamira y Creyer, Rafael. *Historia de España y de la civilización española*, ed. 4, 5 vols., Barcelona, Herederos de J. Gili, 1928-1930.

Ballesteros y Beretta, Antonio. *Historia de España y su influencia en la historia universal*, 9 vols., Barcelona, P. Salas, 1918-1941.

Chapman, Charles Edward. *A History of Spain* (based on Altamira), New York, Macmillan, 1931.

Lafuente, Modesto. *Historia General de España*, continued by J. Valera, 25 vols., Barcelona, Montaner y Simón, 1889-1890.

Madariaga, Salvador de. *Spain*, London, Jonathan Cape, 1942.

Mendizábel, A. *The Martyrdom of Spain*, London, Geoffrey Bles, Centenary Press, 1938 (With an introduction by Jacques Maritain).

Sencourt, Robert. *Spain*, Oxford, 1938.

———. *The Spanish Crown*, Scribner's, 1932.

* These are included for completeness. They are difficult to obtain in American libraries. The material contained in them has been fully covered in articles listed above.

Bibliography of Sources

NEUROLOGICAL REFERENCES *

- Adrian, E D Localization in the cerebrum and cerebellum, *Brit M J* 2 137, 1944
- Aird, R B, and H C Naffziger Regeneration of nerves after anastomoses of small proximal to larger peripheral nerves, *Arch Surg.* 38 906, 1939.
- Alexander, L The fundamental types of histopathologic changes encountered in cases of athetosis and paralysis agitans, *A Research Nerv & Ment. Dis* 21 334, 1941
- Allen, W F Results of prefrontal lobectomy on acquired and on acquiring correct conditioned differential responses with auditory, general cutaneous, and optical stimuli, *Am J Physiol* 139 525, 1943
- Alpers, B J Personality and emotional disorders associated with hypothalamic lesions, *A Research Nerv & Ment. Dis* 20 725, 1940
- Relation of the hypothalamus to disorders of personality, *Arch Neurol & Psychiat* 38 291, 1937
- Arvanitaki, A Effects evoked in an axon by activity of a contiguous one, *J Neurophysiol* 5 89, 1942
- Association for Research in Nervous and Mental Diseases, vol 21 The Diseases of the Basal Ganglia, Baltimore, William & Wilkins, 1943
- vol 23, Pain
- Baggenstoss, A H, J W Kernohan, and J F Drapiefsky The healing process in wounds of the brain, *Proc Mayo Clinic* 19 419, 1944
- Bard, P Neural mechanisms in emotional and sexual behavior, *Psychosom Med* 4 171, 1942
- Bartley, S H Vision—A Study of Its Basis, New York, Van Nostrand, 1941
- Bodian, D The structure of the vertebrate synapse, *J Comp Neurol* 68 117, 1937, 73 323, 1940
- Boeke, J Problems of Nervous Anatomy, New York, Oxford, 1940
- Brain, W R, and E B Strauss Recent Advances in Neurology and Neuropsychiatry, Philadelphia, Blakiston, 1945

* Those most pertinent to this book are annotated All are of value

Bibliography of Sources

- Brenner, C Injuries to peripheral nerves—a review of recent literature, *War Med* 5 21, 1944
- Brickner, R M The Intellectual Functions of the Frontal Lobes, New York, Macmillan, 1936
- Brogden, W J, and W. H Gantt Intraneural conditioning, cerebellar conditioned reflexes, *Arch Neurol & Psychiat* 48 437, 1942
- Brown, J O Nerve regrowth in the central nervous system, *Anat Rec* 94 69, 1946
- Bucy, P C Cortical extirpation in the treatment of involuntary movements *A Research Nerv & Ment Dis* 21 551, 1942
- Effects of extirpation in man, pp 353-394 in *The Precentral Motor Cortex*, Urbana, Univ Illinois Press, 1944
- Cannon, W B The argument for chemical mediation of nerve impulses, in *Chemistry and Medicine*, edited by Maurice B Visscher, Professor of Physiology, University of Minnesota, Univ Minnesota Press, 1940, pp 276-296
- Sums up all the evidence in favor of the chemical theory
- Clark, W E LeGros Visual centers of the brain and their connections, *Physiol Rev* 22 205, 1942
- Modern theories on nervous conduction in retina, optic tract, etc., including analysis of decussation at the chiasma
- Problems of neuronal regeneration in central nervous system, *J Anat* 77 20, 1942, 77 251, 1942
- Account of experiment by Tello on cortical nerve graft with supplementary data on similar work at Oxford (In first of the two articles cited)
- Cobb, S Foundations of Neuropsychiatry, ed 2, Baltimore, Williams & Wilkins, 1941
- Conel, J L The Postnatal Development of the Human Cerebral Cortex, Cambridge, Harvard Univ Press, 1941
- Cooper, S, and C S Sherrington Gower's tract and spinal border cells, *Brain* 63 123, 1941
- Cowdry, E V The neuron, in *Cytology and Cellular Pathology of the Nervous System* (Penfield), vol 1, p 3, New York, Hoeber, 1932
- Davis, L The Principles of Neurological Surgery, Philadelphia, Lea, 1942

Bibliography of Sources

- Denny Brown, D (ed) Selected Writings of Sir Charles Sherrington, New York, Hoeber, 1940
- Erlanger, J The initiation of impulses in axons, J Neurophysiol 2 370, 1939
- Sums up the electrical theory of synaptic transmission
- , and H Gasser Electrical Signs of Nervous Activity, New York, Oxford, 1937
- Forbes, A Problems of synaptic function, J Neurophysiol 2 465, 1939
- Article by professor of physiology, Harvard Medical School Balances the evidence to date with respect to the electrical and the chemical theories of synaptic transmission
- Freeman, W, and J W Watts Psychosurgery, Springfield, Ill, Thomas, 1942
- Fulton, J F Physiology of the Nervous System, ed 2, New York, Oxford, 1943
- Grinker, R R Neurology, ed 3, Springfield, Ill, Thomas, 1943
- Holmes, W, and J Z Young Nerve regeneration after immediate and delayed suture, J Anat 77 63, 1942
- Howe, H A, and D Bodian Neural Mechanisms in Poliomyelitis, New York, Commonwealth Fund, 1942
- King, L S Vital staining of the nervous system, J Anat. 64 177, 1935
- Analysis of results obtained with use of stains on normal and pathological cells
- Kirkman, H, and A E Sevringhaus A review of the Golgi apparatus, Anat Rec 70 413, 1938, 71 79, 1938
- Krieg, W J Functional Neuroanatomy, Philadelphia, Blakiston, 1942
- Larsell, O Anatomy of the Nervous System, New York, D Appleton-Century, 1942
- Lashley, K S Brain Mechanisms and Intelligence, Chicago, Chicago Univ Press, 1929
- Lassek, A M The human pyramidal tract IV, J Comp Neurol 74 217, 1942
- Lewis, T Pain, New York, Macmillan, 1943
- [292]

Bibliography of Sources

Lewis, W H Axon growth and regeneration, *Anat Rec* 91 287, 1945

Account of observation of axon growth with conclusion that the ameboid end of axon lengthens like an ameba pseudopod

Liddell, H S Physiological psychology, *Ann Rev. Physiol* 3 487, 1941

McCouch, G P Conduction and synaptic transmission in the nervous system, *Ann Rev Physiol* 7 455, 1945

Mettler, F A Neuroanatomy, St Louis, Mosby, 1942.

Moniz, E Tentatives opératoires dans le traitement de certaines psychoses, Paris, 1936

Morgan, C T Physiological Psychology, ed 2, New York, McGraw-Hill, 1943

Page, I H Chemistry of the Brain, Springfield, Ill, Thomas, 1937.

Parker, G The Origin, Plan, and Operational Modes of the Nervous System, New York, 1934

Penfield, W The cerebral cortex of man, *Arch Neurol & Psychiat* 40 417, 1938

Article presents clinical evidence that the increase in specialization of certain areas of the cerebral cortex is as striking as the enormous increase in the total quantity of the cortex, and that great differences exist in the cellular arrangement of the various areas

———, and E Boldrey Somatic motor and sensory representation in the cerebral cortex of man as studied by electrical stimulation, *Brain* 60 389, 1937

Ranson, S W The Anatomy of the Nervous System, ed 7, Philadelphia, Saunders, 1943

Renshaw, B Nerve and synaptic transmission, *Ann Rev Physiol* 5 253, 1943

Sherrington, Sir Charles Scott The Integrative Action of the Nervous System, London, Archibald Constable & Co, Ltd, 1906

Scholarly treatise composed of a series of ten lectures on the following co-ordination in the simple reflex, interaction between reflexes, compound reflexes, simultaneous and successive, reflexes as adapted reactions, aspects of the reaction of motor cortex, physiological position and dominance of the brain, sensual fusion

Bibliography of Sources

- *Man on His Nature*, London, Macmillan, 1940
A summary of the contents of this beautifully written and thought-provoking book will give an idea of its scope and character Nature and Tradition The Natural and Superstition Life in Little The Wisdom of the Body Earth's Reshuffling A Whole Presupposed of Its Parts The Brain and Its Work The Organ of Liaison Brain Collaborates with Psyche Earth's Alchemy Two Ways of One Mind Conflict with Nature
- Turnbull, F Pain of cancer from neurosurgeon's viewpoint, *Canad M A J* 45 339, 1941
- Walker, A E Central representation of pain, *A Research Nerv & Ment. Dis* 23 63, 1943
- Walshe, F M R *Diseases of the Nervous System*, Baltimore, Williams & Wilkins, 1944
- Weiss, P Nerve patterns the mechanics of nerve growth, *Growth* 5 (supp) 163, 1941
- White, J C Progress in surgery of the autonomic nervous system, *Surgery* 15 491, 1944
- Wolff, H G Some observations on pain, *Harvey Lectures*, 1943-1944, p 39
- Young, J Z Functional repair of nervous tissue, *Physiol Rev* 22 318, 1942
Analysis of the mechanics of nerve regeneration according to the modern view
- Zilboorg, Gregory *A History of Medical Psychology*, New York, Norton, 1941

- Abd-el Krim, 251, 252
 Acetylcholine, 267
 Achúcarro Nicolás, 209, 232, 239,
 240, 244
 Acicelo, 33
 Adnan, Dr., 161
 Albrecht, Dr., 200
 Alcolea, battle of, 39
 Alfonso XII, 12, 39, 56, 65, 66, 98,
 99, 110, 111, 177, 251
 National Institute of Hygiene,
 202
 Alfonso XIII, 111, 211, 219-225, 233,
 234, 248, 251, 252, 253, 254, 255,
 256, 257
 Amadeo I, 56
 Amanuel, suburb of Madrid, 259
Anales de la Sociedad Española de
 Historia Natural, 159
 Andalusia, 57, 59, 63
 Anesthesia, 265
 Anticholera vaccine, 107
 Antonia, Doña, 4, 27, 30
 Apathy, Dr. S., 207, 228, 229
 Aquinas, St. Thomas, 37
 Aramendia, 94
 Argel, 71
 Argentine Republic, 230
 Aristotle, 37
 Armijo, Marquis de la Vega de, 222
 Arteriosclerosis, 259
 Asis, Francisco de, 11, 12
 Astrocytes, 269
 Asturias, Prince of, 12, 56, 222, 256,
 257
 Axis cylinder, defined, 125
 Axon defined, 124, 125, 147
 growth of, 148, 270
 Ayerza, 13, 17, 18, 22, 24, 30, 35,
 36, 39
 Azáñar, Manuel, 257, 258
 Azcón, 27, 28
 Azoulay, Léon, 149, 152, 161, 208
 Bacteriology, rise of, 46, 109, 110
 Bagá, 70, 75
 Bailo, Mariano, 41
 Ballarín, Florencio, 41, 42
 Balzac, Honoré de, 31
 Barcelona, 57, 61, 122, 146, 153, 211,
 223, 224, 234, 254
 Baroja, Pío, 188
 Baules y Beltrán de Lis, Professor, 153
 Battenberg, House of, 219
 Beatrice, Princess, 219, 220
 Bédard, Pierre Augustin, 42
 Berbers, 223
 Berenguer, General, 254
 Berga, 60
 Berkeley, George, 54
 Berlin, 142, 143, 145, 181
 Bernard, Claude, 130
 Bethe, Albrecht, 172, 207, 211, 212,
 213

Index

- Brelchowsky, Max, 269
 Blanco, Marshal, 185
 Blocking, 266, 268
 Boltzmann, L., 195
 Boston (Mass.), 198
 Bourbon, House of, 10, 41, 55, 100, 177, 220
 Brain anatomy, 126, 132, 143
 Buenos Aires, 216, 238, 240, 255, 258
 Burdeos, 61
 Burgos, 78
 Busto, Marquis del, 157

 Cadiz, 57, 62, 177, 181
 Café de Levante, 156
 Café Suizo, 43, 156, 157, 220
 Calleja, Dr., 157, 189
 Calvin y Martín, Dr., 157
 Camagüey, 65, 68
 Cambridge University, 162, 163
 School of Physiologists, 267
 Cañadás, Angel, 232
 Canalejas y Méndez, José, 184, 224, 225
 Cannon, W. B., 268
 Cánovas del Castillo, Antonio, 99, 110, 177, 185, 234
 Carlists, 59, 65, 66, 98, 99
 Carlos, Don, 57, 59, 66, 98, 111
 Carlotta, 10
 Cartagena, 57
 Casas, Genaro, 47, 48
 Cascorro, 68
 Casino de la Agricultura, 104, 119
 Casino Militar, 137
 Castelar, Emilio, 50, 55, 57, 58, 59, 65, 66, 111, 173, 174, 175, 180
 Castro, Fernando de, 209, 242, 245, 248, 259, 260, 274
 Cataluña, 57, 60, 61, 92, 154, 221, 222, 234, 235, 251
 Catholic Church, 177, 220, 223, 224, 225, 257
 Cell, defined, 125
 basket cell, 137
 cell body, defined, 124, 125
 cell theory, 47
 granule cell, 37
 pyramidal cell, 192, 194
 supportive cells, 270
 Cells of Schwann, 158
 Cellule (la), 158
 Cénarro, 61, 62
 Cerebellum, 131, 149, 150, 229
 Cerebral cortex, 131
 Cerebrum, 131, 151, 189, 192
 Cervantes, Miguel de, 32, 71, 157
Chácharas de café, 259, 271
Charlas de café, 106, 155, 271, 272
 Charles III, 98
 Chateaubriand, François René, Viscount de, 31, 62, 90
 Chemotherapy, 143
 Cholera epidemic, 106-108, 110
 Chrome-silver (silver chromate) method, see Staining methods
 Chromidial substance, defined, 125
 Clark University, 193, 196, 197
 Collateral, defined, 124
 Color photography, 232
 Committee for Widening the Scope of Education, 226, 228
 Committees of defense, 234
 Condillac, Etienne Bonnet de, 37
 Conditioning, defined, 129
 Condorcet, Marquis de, 227
 Conejero, María, 232
 Consciousness, 265
 Constitution, 55, 98, 99, 110, 157, 219, 234, 251, 252, 253, 255, 256, 257
 Contact, transmission of the nervous impulse by, 137, 140
 Cortes, 55, 56, 66, 224, 234, 247, 257, 258
 Creoles, 63, 64
 Croone, William, 160
 Croonian Lecture, 160, 162, 166
 Cruveilhier, Jean, 44
Cuando yo era niño, 271
 Cuba, 10, 60, 61, 64, 69, 71, 79, 83, 90, 97, 98, 156, 183, 184, 185, 186, 187, 195, 196, 198, 253
Cuentos de vacaciones, 233, 271
 Cuaderas, 31
 Cytoplasm, defined, 125

- Daina, Manuel, 16
 Darwin, Charles, 93, 165, 241
 Dato, Eduardo, 225
 Death, 262
 Decussation of optic nerves, 189, 190, 191, 192
 Defoe, Daniel, 32
 Dendrite defined, 124
 Depression 253, 258
 Devere, George, 186
Disco de auros, 173
 'Doctor Brictenr' 113, 233
 Doctrine du neurone—*théorie et faits*, 218
 Don Quixote, 32, 271
 Dreams, 261
 Dumas, *1^{er}*, 31, 32
 Duval Mathias, 149, 152, 161
 Dynamic potential of the neuron, theory of, 146, 164, 168
 Echegaray, José, 43
 Medal, 247
 Edinger, Ludwig, 143, 168, 236
 Edison, Thomas A., 199
 Education, 145, 166, 225, 226, 257, 267, 268
 Edward VII, 219, 220
 Effectors, 127
 Ehrlich, Paul, 143, 172, 189, 236, 255, 269
 Embryo, use of, 135, 168, 207, 208
 Embryologists, 144
 Ena, 219, 220, 221, 256
 England, 160-166, 220, 226
 Ependyma, 238
 Esculapian fathers, 20, 21, 26
España (ship), 62, 77, 246
 Espronceda, José de, 31, 50
Estudios sobre la degeneración y la regeneración del sistema nervioso, 230
 Eugénie, Empress, 39, 220
 Evolution, theory of, 93
 of the nervous system, 127, 169, 171
 Fabre, Jean Henri, 43
 Facilitation, 264
 Fañanás García, Silveria, 97, 101, 195, 198, 259, 262
 Fauvelle Prize, 182
 Fenollo, 35
 Ferdinand VII, 10, 41, 57
 Ferrán, Dr., 107, 108
 Ferrer, Francisco, 223, 224
 Ferner, David, 166
 Final common path, 128, 264
Fine structure des centres nerveux (la), 161
 Flechsig, Paul, 170
 Fotel, Auguste Henri, 138, 139, 195
 Foster, Michael, 161, 163, 165
 France, 10, 11, 223
 Franco, Francisco, 258
 Franco Prussian war, 56
 Frankfurt am Main, 143
 Free endings, theory of, 138, 139
 Gargha, 130, 229
General Considerations on the Morphology of the Nerve Cell, 169
 Genetics, 209
 Gerlach, Joseph von, 138, 211
 German Anatomical Society, 142-144
 Gimeno, Amalio, 201, 260
 Giner de los Rios, Francisco, 177, 178, 179, 180, 227
 Gland, defined, 127
 Glia, 238, 269, 270, glia stain, 269
 Gliomas, 269
 Goethe, Johann Wolfgang von, 32
 Golgi, Camillo, 132, 133, 134, 135, 138, 139, 142, 144, 145, 148, 149, 159, 168, 211, 215, 217, 218, 219, 228, 231, 269
 network theory, 138
 reticular apparatus, 125, 231
 staining method, 131, 132, 133, 148
 Gómez, Dr., 157
 Göttingen, 145
 Granada, 57, 89, 93, 94, 100, 155
 Grau, Dr., 68, 69, 70, 75
 Gray matter, 126, 170
 Growth cone, 148
 Guam, 187

Index

- Habit formation, 268
 Haeckel, Ernst, 93
 Hall, G Stanley, 196, 197
 Hallucinations, 171, 266
 Havana, 63, 69, 185, 186
 Hearst, William Randolph, 185
 Held, H., 152, 168, 228, 229
 Helmholtz, Hermann Ludwig Ferdinand von, 210
 Medal, 210
 Hemophilia, 220, 222, 253
 Henle, Friedrich Gustav Jakob, 51
 Hippocampus, 157, 158, 159
 His, Wilhelm, 138, 139, 145, 147, 149
Histología, 112
 Histologists, 144, 242
 Histology, 84, 85, 109, 110, 112, 114, 157, 235, 261, 270
 Hohenzollern-Sigmaringen, Leopold of, 56
Holiday Tales, 233, 271
 Huesca, 3, 13, 20, 26, 27, 28, 29, 32, 41
 Hugo, Victor, 31, 32, 50, 90
 Huxley, T H., 93
 Hypnotism, 119
 Hysteria, 265

 Illusions, 266
 Immunity, 143
 Inhibition, 129, 264, 268
 Instincts, 268
 Institución Libre de Enseñanza, 178
 Instituto Cajal, 244, 248, 249, 259, 260
 Integration, 268
 International Medical Congress, 169, 199, 203, 226
 Isabel II, 9, 10, 11, 12, 34, 35, 38, 39, 55, 56, 57, 59, 98, 99
 Isabel, Infanta, 12
 Italy, 145, 203, 251

 Jaca, 13, 20, 21, 23, 255
 Jacinto, Father, 22, 23
 Jimeno, Joaquín, 50
 Junta para Ampliación de Estudios, 226, 228

 Justo, Don, 16, 17, 18, 20, 21, 24, 25, 26, 30, 33, 36, 37, 38, 40, 41, 43, 44, 48, 61, 62, 76, 90, 91, 95, 96

 Kelvin, William Thomson, Lord, 162, 210
 King's College, 162, 163
 Koch, Robert, 104, 106, 108, 143
 Kölliker, Albrecht von, 51, 88, 144, 147, 159, 160, 168, 182, 189, 191
 Krause, Wilhelm, 117, 145, 236
 Krausist philosophy, 176, 177
 Kuppfer, Wilhelm, 147

 Laboratorio de Investigaciones Biológicas, 203, 235, 237, 243
 Laboratory of Normal and Pathological Histology, 271
 Lafora, Dr., 209
 Lamartine, Alphonse Marie Louis de, 31, 90
 Langley, John, 164
 Larrés, 3, 5
 Latin America, 200
 Lawrence, Thomas, 160
 Ledesma, Francisco, 69, 89
 Lenhossék, Michael, 149
 Lérida, 59
 Lerroux, 255
 Le Sage, Alain René, 31, 32
 Letamendi, Dr., 101, 157
 Limás de Marcuello, 35, 36
 Lite, Dr., 107
 Lithographic printing, 93, 101
 Llobregat, 60
 Lluna, Dr., 182
 Localization of cerebral functions, 193, 265
 Locke, John, 37
 London, 160-166
 Louis Napoleon, 65
 Louis Philippe, 11
 Louvain, 145, 236
 Lubbock, John, 164
 Lugaro, Ernesto, 273
 Luisa Fernanda, 11, 99
 Luna, 5
 Lyautey, Louis Hubert Gonzalve, 252

- McKinley, William, 185, 186, 197
 Microglia, 238
 Madariaga, Salvador de, 98, 179
 Madrid, 30, 66, 78, 81, 82, 95, 100,
 101, 110, 123, 133, 152, 154, 155,
 167, 173, 176, 177, 178, 200, 211,
 244, 255, 258, 271
 Maestro y lo (el), 238
 Maine, 185
 Málaga, 57
 Malaria, 67, 76, 132
 Manresa, 60
 Marín de Zumiga General, 36
 Manual de histología normal y técnica
 micrográfica, 112
 Mariñón, Gregorio, 255
 Marchi, Vittorio, 185
 María Cristina (Bourbon), 10, 12
 María Cristina (Hapsburg), 100, 110,
 111, 185, 201, 219, 220
 Mariana Juan de, 31
 Marie-Amélie, 11
 Marital, 163
 Martínez, Vargas, Dr., 228
 Mauri, Antonio, 222, 224, 234
 Maura Miguel, 255, 257
 Maximilian, 10
 Mazo, Cipriano de, 165
 Medizábel, Alejandro, 53
 Medulla, 131, 168, 229
 Melilla, 223, 251
 Memory, 265
 Menéndez Pidal, Ramón, 227, 271
 Mental diseases, 143, 266
 Mercedes, 99, 100
 Menno, Miguel, 181
 Merry del Val, Rafael, 211
 Metchnikoff, Elie, 109
 Methylene blue, *see* Staining methods
 Mexico, 10
 Meynert, Theodor, 118, 170
 Michel's theory of decussation, 189
 Microbiology, 106
 Microglia, 238, 240, 244, 265
 Microscopy, 88, 112
 Midbrain, 131
 Moltó, Puig, 12
 Monlora, 5
 Montello, Nicolás, 46
 Montpensier, Duke of, 11, 99
 Montreal Neurological Institute, 249
 Moret, Sepismundo, 184, 185, 222,
 224, 225, 226
 Moroccan war, 10, 12, 34, 223, 251,
 252
 Morocco, 9, 10, 223, 224, 251, 258
 Morral, 221, 223
 Monones, José, 51, 52
 Moriones, General, 34
 Morro Castle, 63
 Moscow Prize, 199, 200
 Moscow, A., 195
 Mountbatten, House of, 219
 Mujer (la), 271
 Muley el Abbas, 9
 Mundo visto a los ochenta años (el),
 259, 260, 271
 Muñoz, Fernando, 10, 11, 12
 Muscle, defined, 127
 Museo Antropológico, 248
 Mussolini Benito, 251, 252
 Myelin, defined, 125
 sheath, 125, 126, 158, 270
 Napoleon III, 65
 Naráez, 10, 38
 National Institute of Hygiene of Al
 fonso XII, 237
 Nerve, defined, 125
 cell, *see* Neuron
 fiber (process), 124, 125, 137,
 140
 Nervous
 degeneration, 166, 229, 270, 271
 impulse, mediation of, theories,
 267
 pathology, 126, 143, 209, 266
 regeneration, 158, 212-214, 229,
 230, 270, 271
 response, 127
 stimulus, 127
 Nervous system
 autonomic, 130
 central, 130
 development, 136, 146, 147, 148,
 158, 171, 210, 211
 divisions, 130
 function, 127

Index

- Nervous System (*cont*)
 peripheral, 130
 structure, 124, 152
 Network theory, 138, 141, 144, 148,
 171, 173, 207, 211, 218
 Neural avalanche, 171
 Neuronlemma, 126, 213
 Neurobions, defined, 213
 Neurofibrils, 125, 204, 206, 207, 228,
 237, 244, 269
 Neuroglia, 125, 232, 238, 265
 Neurology, 118, 140, 148, 212, 263,
 264
 Neuron, defined, 124, 125, 141
 associational (adjustor), 127, 149
 doctrine, 141, 148, 211, 212,
 214, 229, 249, 264
 motor (efferent), 127, 229
 sensory (afferent) 127, 229
 with short axon, 193, 194
Neuronismo o reticularismo?, 262
 Neurotropic
 substances, 158
 theory, 148, 157, 229, 230, 260,
 262
 Neuropsychiatry, 266
 Neurosurgery, 127, 266
 Newton, Isaac, 165, 189
 New York, 195, 196, 199
 Nietzsche, Friedrich, 117
 Nissl's granules, 125
 Nó, Lorente de, 245
 Nobel, Alfred, 217
 Nobel Foundation, 216, 217
 Nobel Prizes, 43, 161, 215, 216,
 228, 249
*Nouvelles idées sur la fine anatomie
 des centres nerveux*, 192
 Nucleus, defined, 125
 Nuevitas, 65
 Ocaña, Dr., 157
 O'Donnell, Leopoldo, 9, 10, 38
 Olfactory bulb, 150
 Oligodendroglia, 238, 244, 269
 Olónz, Federico, 100, 101, 155, 157,
 187, 255
 Optic center, 241
 Optic chiasma, 189
 [300]
 Orovia y Echagüe, Manuel, 177
 Ortega y Gasset, José, 255
 Oscar II, 217
 Oxford University, 162, 163, 164, 230
 Palladino, Eusapia, 261
 Panticosa, 91
 Pardini, 225
 Paris, 149, 200, 257
 Paseo de Atocha, 243, 248
 Pasteur, Louis, 104, 109, 250
 Pau, 39
 Pavia, 145
 Pavia, General, 59, 65, 66
 Pavlov, Ivan Petrovich, 129, 268
 Penfield, Wilder, 249, 261, 275
Pensamientos escogidos, 271
 Pérez de Ayala, Ramón, 255
 Pérez Galdós, Benito, 225
 Peridendrite spines, 137
 Petilla, 2, 4
 Philippine Islands, 183, 186, 187, 198
 Phonograph, 199
 Photography, 84, 92, 93, 101, 119,
 232, 237
 Picard, E., 195
 Pierrad, General, 34
 Pi-Suñer, Augusto and Jaime, 264
 Pius IX, 98, 111
 Pí y Margall, 57, 175, 184
 Platt Amendment, 187
 Poblador, 51, 52, 53
 Polak, Moises, 238, 240
 Polanzation, theory of dynamic, 150,
 151, 267
 Pons, 131, 168
 Popular Front, 258
 Prado (el), 155
 Prim, Juan, 9, 10, 34, 38, 39, 56
 Primo de Rivera, Miguel, 98, 250,
 251, 252, 253, 254
 Protoplasm, 116, 125, 265
*Psicología de Don Quijote y el qui
 jotismo*, 271
 Psychoanalysis, 266
 Psychology, 118, 126, 132, 164, 169,
 170, 171, 198, 261, 264, 268
 Puerto Príncipe, 65, 68, 69, 74, 75,
 76

- Puerto Rico, 186, 187
 Pyrenees, 13
- Quatro Caminos, district, 200
 Quevedo, Francisco, 31
- Rabies, 208
 Ramón Casassus, Justo, *see* Justo, Don
 Ramón y Cajal (Pedro), 5, 18, 33, 34, 61, 150, 181, 189, 204
 Ramón y Cajal (Santiago)
 autobiography, 229
 birthplace, 2, 4
 books, *see under* titles
 brothers and sisters, 5, 18, 33, 34, 61, 91, 92, 150, 181, 189, 204
 children, 97, 103, 107, 119, 137, 146, 150, 154, 232, 260
 parents, *see* Antonia, Doña, and Justo, Don
 wife, 97, 101, 195, 198, 259, 262
 See also Neuron doctrine, Polarization, etc
- Ranvier, Louis Antoine, 84, 88, 93, 118, 131
 Receptors, 127
Recuerdos de mi vida, 188, 189, 271
 Reflex arc, 127, 268
 conditioned, 129, 170, 268
 Regeneration, Era of, 188
Reglos y consejos, 181, 182, 227, 244, 271
 Response, 127
 Restoration, 65, 99, 100, 177
 Reticular hypothesis, *see* Network theory
 Retina, 150, 151, 157, 158, 171, 241
 Retro (el), 156, 248
 monument, 248
 Retzius, Magnus Gustav, 144, 149, 161, 215, 217, 236
Revista trimestral, 136, 142, 180, 181, 203
 Revolution, 38, 55, 66, 173, 177
 Rhinencephalon, 159
 Ruano, Facundo, 167
 Ruff war, 223, 251, 252
- Ruo Hortegea, Pío del, 232, 237, 238, 239, 240, 241, 244, 249, 261, 269
 Ríos, Ramón, 81
 Ríoz, Dr., 82
Robinson Crusoe, 32
 Romanones, Count, 221, 225, 233
 Rome, 169, 226
 Roosevelt, Theodore, 185, 217
 Rousseau, Jean Jacques, 37
 Royal Academy of Medicine, (Madrid), 182
 Royal Academy of Music (Stockholm), 217
 Royal Academy of Science
 Berlin, 210
 Madrid, 181, 248
 Royal Caroline Institute (Stockholm), 215
 Royal Society of London, 160, 165, 275
 Rubio Prize, 182
- Sagasta, Praxedes Mateo, 99, 110, 111, 112, 184, 185, 234
 Sagunto, 66
 Saint Pierre, Bernardin de, 62
 Sala y Pons, Dr., 189
 Salisbury, Stephen, 196
 Sallent, 60
 Salmerón, Alfonso, 57, 175, 176
 Salmon, D. E., 108
 Salvatsan, 143, 255
 San Carlos, College of, 95, 152, 157, 167, 255
 Sánchez, Domingo, 241, 245
 San Isidro, 70, 73, 74, 75
 San Jerónimo, 220
 San Juan, P. R., 63
 de la Peña, 91, 92
 San Miguel de Nuevitas, 70
 San Sebastian, 38, 252
 Santander, 77, 78
 Sappey, Marie Philibert Constant, 44
 Schopenhauer, Arthur, 116
 Schultze, Max, 270
 Schwalbe, Gustav, 118
 Schwann, Theodor, 47, 114, 213
 Second French Empire, 56
 Semac, 41

Index

- Sense organ, 127
Serrano, Francisco, 11, 12, 38, 39, 56,
57, 66, 110
Seville, 57
Sheath of Schwann, 126, 213
Sherrington, Charles Scott, ix-xv,
161, 162, 164, 267, 275
Silvela, Francisco, 201, 202
Silveria (Fañanás y García), 97, 101,
195, 198, 259, 262
Silvestre, General, 251
Simarro, Luís, 133, 134, 245
*Sistema nervioso del hombre y de los
vertebrados (el)*, 152
Sleep, 265
Smell brain, 159
Smith, Theobald, 108
Socialists, 234, 255, 258
Society of Biology (Paris), 182
Solano, Bruno, 42, 43
Sorbonne, 271
Sorolla y Bastida, Joaquín, 242
Spain, history of
 Civil War, 255, 258, 260
 First Spanish Republic, 58, 59,
 65, 66, 175
 Regency, 110-112
 reign of Alfonso XII, 98-100
 reign of Alfonso XIII, 219-225,
 233-235
 reign of Isabel II, 9-13
 Restoration, 65, 99, 100, 177
 Second Spanish Republic, 256,
 257
 September revolution, 38-39
 Spanish-American war, 183-
 189, 198, 199
 World War I, 233
Spain, map of, 15
Spanish-American war, 183-189,
198, 199
"Spanish marriages," 11
Spanish school of histologists, 242,
244, 245, 248, 271
Spanish surnames, 3
Spencer, Herbert, 116
Spinal cord, 126, 127, 130, 149, 150,
229
Staining methods
 ammoniacal silver nitrate, 85,
 269
 chrome silver, *see* "silver stain"
 below
 gold chloride, 85
 gold sublimate, 232, 269
 methylene blue (Ehrlich's), 143,
 172, 189, 269
 silver carbonate, 238, 239
 silver nitrate, 269
 "silver stain" (Golgi's), 131-133,
 142, 144, 148, 173, 203, 269
 transparent (reduced silver ni-
 trate), 203, 205, 208
 uranium nitrate, 231
Stimulus, 127
Structures et connexions des neurones,
218
*Studies of the Degeneration and the
Regeneration of the Nervous Sys-
tem*, 230
Sue, Eugène, 31
Suffrage movement, 196-197, 198,
257
Summation, 128, 264
Sydenham, Thomas, 106
Sympathin, 267
Synapse, 128, 268
Syphilis, 206
Tangier, 62
Tárrega, 60
Tello, Francisco, 189, 204, 207, 214,
230, 242, 244, 247
Terminal arborizations, defined, 124
Tetuán, 9, 13
Textura del sistema nervioso, 193,
208, 270
Thalamus, 131, 168
"Third element," 237, 238, 239, 240,
269
Topete, Admiral, 39
*Trabajos del laboratorio de investiga-
ciones biológicas*, 181, 203
Trochas, 71
Tuberculosis, 143
Tudela, Tomás Pérez de, 232

- Tumors and cancer, 172, 269
 Tyndall, John, 43
- Unamuno, Miguel de, 253
 United States, 10, 72, 183, 184, 185,
 187, 193, 196, 197, 236
 Upsala University, 219
 Uruguay, 61
- Vaccination, 108
 Valencia, 57, 97, 100, 101, 102, 103,
 105, 106, 107, 110, 112, 118, 123
 Valpalmas, 5, 13
 Van Gehuchten, Arthur, 145, 148,
 150, 168, 204, 212, 214, 236, 273
 Valle-Inclán, Ramón de, 188
 Ventura, Don, 37
 "Venus de Milo," 52, 53, 54
 Verne, Jules, 50
 Vicién, 38
 Victor Emmanuel II, 56
 Victoria, Queen, 11, 219, 220
 Victoria Eugénie, *see* Ena
 Vienna, 195, 200
 Villaluenga, 69
 Villaverde, Dr, 245
- Vinci, Leonardo da, 19
 Virchow, Rudolf, 46, 47, 114, 161,
 181, 210
 Vision, types of, 191
 Vista Hermosa, 65, 66, 68, 70
 Vizarra, J Gimeno, 173, 174, 175
 Voltaire, François Marie Arouet, 37
- Wagner, Richard, 156
 Waldeyer, Wilhelm, 87, 141, 145,
 149, 210, 212, 236
 Waller, Augustus, 212
 Weigert, Karl, 143, 191, 270
 Weismann, August, 179
 Weyler, Valeriano, 185, 224
 White matter, 126
 Worcester (Mass), 193, 196, 198
 World War I, 157, 233, 235
 Wurzburg, 182
- Zamora, Alcalá, 255, 256, 257, 258
 Zaragoza, 20, 41, 43, 61, 78, 80, 81,
 82, 89, 93, 94, 95, 107, 108, 109,
 112, 122, 154, 173, 261
 Zonilla, José, 50